The biomechanics of military load carriage and injury potential

The Biomechanics of Military Load Carriage
and Injury Potential

By

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Abstract

This thesis consisted of two main research themes: 1) The biomechanics of military load carriage, and 2) injuries and discomfort caused by load carriage. Although different in their methodological approaches, the two sections are linked and integral to each other. Harman et al (2000) suggest that the biomechanical analysis of military load carriage, and in particular the study of ground reaction forces (GRF), is relevant to the understanding and prevention of lower extremity injuries.

The general aims of the biomechanical analysis of load carriage were to determine the effect that heavy load carriage, rifle carriage and load distribution has on GRF parameters. In addition to determining the mechanisms behind these potential changes, base-line data for British military load carriage systems (LCS) were also established. An important factor for the thesis was to consider the LCS as a single unit (where possible) and not its individual components, for example the backpack alone. The final biomechanical study involved a 3D, bi-lateral gait analysis of load carriage; with this type of analysis being rare in the published literature.

Results from the biomechanical studies showed that GRF parameters increased proportionally to applied load, even when heavy loads of up to 40 kg were carried. Also seen was an increase in mediolateral impulse and stance time with greater carried load. Another area which has received little or no attention in the literature is the effect of rifle carriage on gait. This thesis showed that rifle carriage changed basal gait patterns as observed in the GRF parameters. The most noteworthy results were an increase in impact peak and mediolateral impulse. The mechanism behind these changes is most likely to be a restriction of natural arm swing induced by rifle carriage. Distributing load more evenly around the body had limited effect on the GRF parameters measured. However, some important changes were observed. These were an increase in force minimum and a decrease in maximum braking force at the heaviest load. The latter effect has been strongly linked to an increase in the incidence of foot blisters within the literature. Finally, the gait analysis study showed significant increases in joint moments and torques with carried load. Also observed was a decrease in stride length and increase in percentage double support and stance. The main kinematic differences were a decrease in range of motion at the knee and pelvis rotation, and an increase in pelvis tilt as load is added.

Four further studies were conducted in an effort to determine the discomfort and injury caused by load carriage. The first 3 studies collected subjective discomfort data via interviews, questionnaires and the use of comfort ratings. All of which were collected either during or after a prolonged period of load carriage by military personnel. Results gleaned from these studies showed that the upper limb is susceptible to short term discomfort following load carriage, whereas the lower limb is not. The lower limb may be at an increased risk of developing medium to long term injuries such as joint degradation and stress fractures. However, foot pain was rated as the most uncomfortable skeletal region of the body following a 1 hour field march with load, and blisters were experienced by around 60% of participants. Shoulder discomfort commences almost as soon as load is added and increases steadily with time. However, foot discomfort seems to increase more rapidly once the discomfort first materialises. This early development of shoulder or foot pain may be a risk factor for severe pain or non-completion of a period of prolonged load carriage. Finally, females experienced more discomfort in the hip joint and feet compared to males. The final study was a questionnaire survey, conducted among 100 students and staff at a military college. The aim of this was to collect quantitative data on injury incidence and prevalence for this group of participants as a result of load carriage. Results showed that lower back injuries were common amongst students and staff. The main issues concerning students was load carriage causing discomfort at the shoulders, increasing general fatigue or causing the onset of a previous injury.

The thesis concludes that load carriage alters gait patterns which can increase injury risk. Injuries as a direct result of load carriage are mainly limited to upper limb discomfort, back pain and blisters. However, load carriage increases impact forces which have been linked to the development of overuse injuries. Further research is needed to establish quantifiable links between load carriage and overuse injuries, with longitudinal studies needed to establish the extent of load carriage related injuries.

Keywords: Load Carriage, Military, Biomechanics, Injury, Discomfort, Rifle Carriage.

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Finally, thank you to Amy. You have helped me so much though this process, moving to Loughborough all those years ago started our little adventure. Also for reading my thesis and pointing out all those little mistakes I keep missing. However, I will be glad never to read 'check tense' in the margin ever again. Xxx.

Publications

Work presented in this thesis has been accepted for publication and published in peer-reviewed journals, presented at national and international conferences.

- Birrell, S.A, Haslam, R.A. 2008. Military load carriage injuries and discomfort. The Ergonomics Society Annual Conference, University of Nottingham, UK. (April 1-3, 2008).

- Birrell, S.A., Haslam, R.A. In Press. The influence of rifle carriage on the kinetics of human gait. Accepted for publication in Ergonomics, 15th November 2007.

- Birrell, S.A., Hooper, R.H., Haslam, R.A. 2007. The effect of military load carriage on ground reaction forces. Gait & Posture, 26(4), 611-614.

- Birrell, S.A., Hooper, R.H. 2007. Initial subjective load carriage injury data collected with interviews and questionnaire. Military Medicine, 172(3), 306-311.

- Birrell, S.A., Haslam, R.A. 2006. The effect of rifle carriage on ground reaction force parameters. 2nd Annual Injury Biomechanics Symposium, The Ohio State University, Columbus, OH. (May 17-19, 2006).

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Chapter One – Introduction

1.1 Introduction

Human factors military load carriage research has historically had the overall aim of improving the efficiency of the load carrier, in this case the soldier. Load carriage is an inevitable part of military life both during training and operations, with loads carried frequently being as high as 60% of bodyweight. Decreasing the load carried by soldiers is not a likely prospect due to technological advancements and constant enhancement to soldier systems for lethality, protection, communications, sustainability and mobility. Therefore the main research focus has been on improving load carriage system (LCS) design to compensate for the increasing load. Underpinning the decisions made by designers is the work done by researchers which benchmark current behaviour, derive optimal performance and ultimately will test the new design on the end user. Military load carriage research can be generally split into 5 categories, these are:

- Improving the ergonomics of a LCS (fit, access, integration and usability).
- Increasing task performance (grenade throw and shooting accuracy, obstacle course or run times).
- Optimising the physiological efficiency of load carriage (energy cost).
- Increasing user comfort and minimising injury during and after load carriage.
- Reducing biomechanical stress placed on the body (impact and moment forces, forward lean, peak pressures, muscle recruitment).

Under the guidance of Dr Robin Hooper, Loughborough University has an excellent recent history of research into the ergonomics of military load carriage. Previous work has focused on the use of exoskeletons to support load on the body (Tilbury-Davis, 1999). Other work has concerned the development of innovative methods to measure interface pressures and evaluation of novel load carriage designs

(Martin, 2001). This research was advanced by Jones (2005) who investigated the effect of changing LCS design and subsequent effects on interface pressures. Most recently Attwells (2006) investigated the effect of load carriage on gait and posture. This current thesis adds further to knowledge and understanding of work conducted at Loughborough University and at other research centres around the world.

This thesis adopted a two staged approach to further investigate questions regarding military load carriage. The thesis tackled the biomechanics of military load carriage, with particular reference on the kinetics of human gait. In addition to this, injuries and discomforts as a result of load carriage were also evaluated. Injury and biomechanics are integrally linked as the study of ground reaction forces (GRF) during walking can provide relevant information about the mechanisms of gait and provides a measure of the impact forces on the foot. Harman et al (2000) suggest that the knowledge of the biomechanics of military load carriage is therefore essential in the understanding and prevention of lower extremity injuries. Although the two topics of biomechanics and injury are connected, actual proven scientific links between increases in impact forces and the development of injuries have not been fully demonstrated. Only theoretical links and risk factors have been published in the available literature.

The standard issue LCS currently used by British troops is the '90 Pattern LCS. This was developed following the Falklands War where the previous LCS, the '58 Pattern, was deemed inadequate. The '90 pattern was issued in 1988 and has been in use ever since under various guises. Another overhaul of the British LCS is currently being undertaken by the Defence Science and Technology Laboratories (Dstl), as part of the Future Integrated Soldier Technology (or FIST) programme. The goal is to integrate a modular system of all equipment, weapons, sighting systems and radios that the individual soldier carries or uses, in order to increase his overall effectiveness on the battlefield. The equipment should be ready for issue in 2008/9 and issued to those who require it between 2015 and 2020. Research outcomes from this thesis will feed into the FIST programme, contributing to the understanding of how changes in LCS can affect impact forces, joint kinematics, subjective levels of comfort and ultimately injury incidence and prevalence.

1.2 Aims and Objectives of Thesis

As mentioned previously this thesis has two distinct sections; biomechanics and injury/discomfort. Therefore each section has its own aims and objectives which will help achieve the overall objective of the thesis.

Overall Aims of the Thesis

1. Evaluate the effects that load carriage has on the biomechanics of human gait.
2. Determine the incidence and prevalence of load carriage related discomfort and injuries within the military.
3. Establish and appraise biomechanical risk factors for injury.

Biomechanics

1. Evaluate the effect that heavy load carriage, rifle carriage and load distribution has on the kinetics of human gait.
2. Conduct 3D, bi-lateral gait analysis of load carriage, incorporating the collection of kinematic, kinetic and spatiotemporal data.
3. Benchmark, record and distribute to the scientific community the biomechanical effects of military load carriage using UK standard issue equipment.
4. Establish which biomechanical parameters may be linked to the development of injuries, and ascertain how load carriage affects these parameters.

Injury/Discomfort

1. Determine and review the typical discomforts resulting from load carriage.
2. Examine the incidence and prevalence of load carriage injuries in the military.

The methodologies adopted to fulfil the aims of this thesis included lab based studies to review the biomechanical aspects, using gait analysis equipment. Subjective injury and discomfort data were collected both in-field and in the laboratory, using questionnaire and interview techniques.

1.3 Structure of Thesis

This thesis consists of twelve chapters. The first half of the thesis will focus on the biomechanics of military load carriage, the second half on injury and discomfort. Chapters 2 and 8 review the scientific literature regarding biomechanics and injury of load carriage, respectively. Chapter 3 outlines the methods used to collect the quantitative and qualitative data throughout the thesis. Experimental work conducted for this thesis consisted of eight studies, four biomechanical and four regarding injury and discomfort. Chapters 4, 5, 6 and 7 present the results from the laboratory based studies regarding the effect of heavy military load carriage, rifle carriage, load distribution and gait analysis of load carriage. Chapter 9 combined two studies concerned with the collection of initial load carriage discomfort data collected by interviews and questionnaires. Chapter 10 reports data from an in-field load carriage exercise where skeletal discomfort was assessed. The final injury and discomfort study is presented in chapter 11. The research presented in this chapter determined the incidence and prevalence of load carriage related injuries for that particular group of participants, while also reviewing load carriage discomfort. Finally, chapter 12 summarises the findings from the thesis and present ideas for future research.

Chapter Two – Biomechanics of Military Load Carriage: Literature Review

2.1 Introduction

The title of this thesis is 'The biomechanics of military load carriage and injury potential'. Load carriage could be assessed using many biomechanical parameters, including pressure measurement and muscular activity. This thesis focuses on the kinetic and kinematic parameters, culminating in a 3D, bi-lateral gait analysis of load carriage. This chapter reviews the pertinent literature surrounding the topic of the biomechanics of military load carriage, and also reviews the effects of rifle carriage. Chapters 4 to 7 will proceed to investigate numerous issues relating to military load carriage, in a lab based setting. This chapter will review and discuss research methods and conclusions from relevant literature, thus providing background for the experimental chapters that follow.

2.2 Kinematic Effects of Load Carriage

2.2.1 Introduction

Biomechanics is generally split into 2 distinct types of data collected; either kinetic or kinematic. Kinematics deals with the spatial (position) and temporal (time) components of motion. They involve the measurement of position, velocity and acceleration of a body with no concern for the force causing motion (Hamill and Knutzen, 1995). The primary use of kinematics for researchers is to provide a quantitative description of gait, allowing precise measurement of human movement. In terms of human gait analysis, markers are usually placed on key body positions to define segments of the upper and lower limb, as well as the trunk and head. The position in space of these markers is then tracked and subsequent values calculated. The defining of body segments also allows the measurement of joint angles. The primary use of kinematics in research is to establish or determine changes and alteration from 'normal' or control values. This section of the literature review will focus on the effect of load carriage on the kinematic parameters.

2.2.2 Body Posture and Joint Angles

Trunk Angle

The principal parameter when considering load carriage and body posture is trunk angle, also known as forward lean. It is a measure of the erect or incline position of the trunk and is calculated relative to the vertical. Forward lean can be measured from the greater trochanter, pelvic girdle or lower back to the C7 or shoulder. It is well established within the literature that load carriage causes forward lean, and the greater the carried load the greater the forward lean (Kinoshita, 1985; Martin and Nelson, 1986; Harman et al, 1994; Goh et al, 1998; Harman et al, 2000; Filaire et al, 2001; Polcyn et al, 2002; Attwells et al, 2006). Figure 2.1 shows a illustration of the how trunk angle decreases as load is added, the studies shown on the figure all carried load in backpacks. The carriage of heavy loads is a risk factor for the development of back and other injuries. These may be as a result of this forward lean as the increase in torque on the lower back needs to be resisted by the back muscles (Knapik et al, 2004). Changing the load placement or distribution also has significant effects on trunk angle and kinematic parameters; this is discussed later in section 2.4 of this literature review.

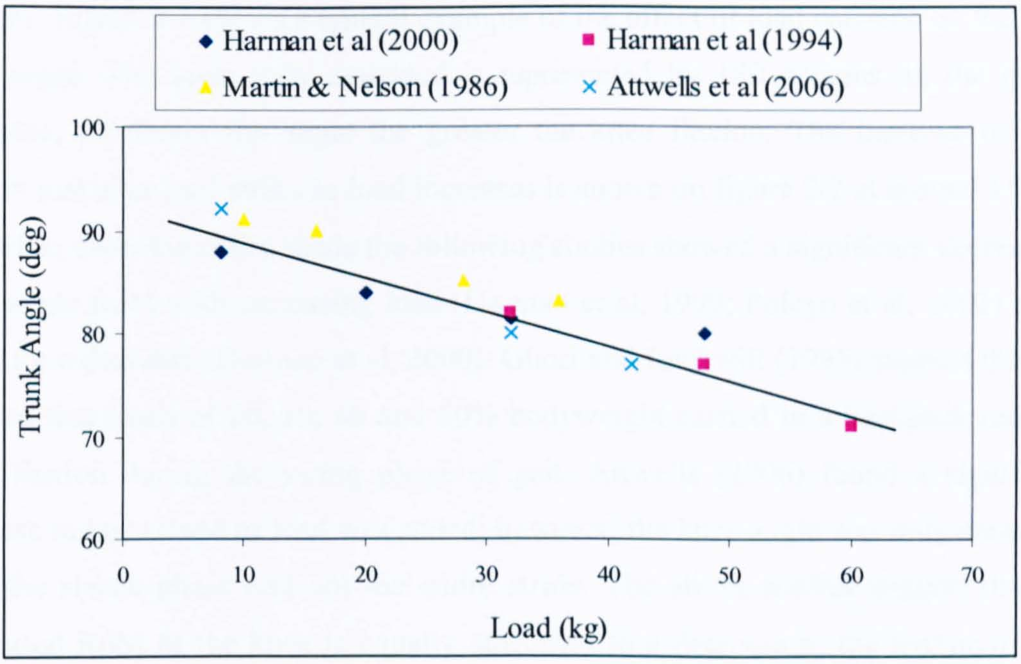


Figure 2.1: Decrease in trunk angle as load is added.

Although trunk angle is the most frequently measured kinematic parameter it is by no means the only one. Other parameters include angles of the lower limb (pelvis, hip, knee and ankle), the upper limb and head include craniovertebral, craniohorizontal, shoulder and elbow. These angles are more commonly measured in the sagittal plane, therefore measuring flexion and extension of a joint. However, they can also be assessed in the frontal and transverse planes, measuring movement towards and away from the midline of the body and joint rotations respectively.

Knee Angle

The angle of flexion and extension of the knee is considered very important in load carriage kinematics based on two beliefs. Firstly, that increased knee flexion just after heel strike helps to absorb shock forces transmitted from the foot during heel strike until mid-stance (Kinoshita, 1985; Harman et al, 2000). Secondly, that greater knee flexion helps keep the body's centre of mass (CoM) lower, thus increasing stability as load increases (Harman et al, 2000).

A change to the range of motion (RoM) of the knee with increasing load carriage has received mixed results in the available literature. While an increase in knee flexion has been observed to coincide with the impact peak with greater load (Kinoshita, 1985; Holmes et al, 1999; Harman et al, 2000), changes to the RoM is not so clear. Figure 2.2 shows a typical example of the effect of load carriage on the knee joint angle. The knee fully extended is represented by 180 degrees on the graph; therefore, the lesser the angle the greater the knee flexion. The increase in knee flexion just after heel strike as load increases is shown on figure 2.2 at around 15% of the stride. Over the entire stride the following studies showed a significant decrease in knee angle RoM with increasing load (Harman et al, 1999; Polcyn et al, 2002) and a trend for a decrease (Harman et al, 2000). Ghori and Luckwill (1985) support this and showed that loads of 20, 30, 40 and 50% bodyweight carried in a backpack reduced knee flexion during the swing phase of gait. Attwells (2006) found a significant increase in knee RoM as load was added; however, the knee angle was only measured over the stance phase and not the entire stride. The above studies suggest that the decreased RoM of the knee is equally attributed to a decrease in the maximum and increase in the minimum knee angle. Polcyn et al (2002) suggest that the RoM of the knee increases by 0.01 degrees with every 1 N decreases in load, and state that 'load being carried does have a linear effect on the movement of the knee.'

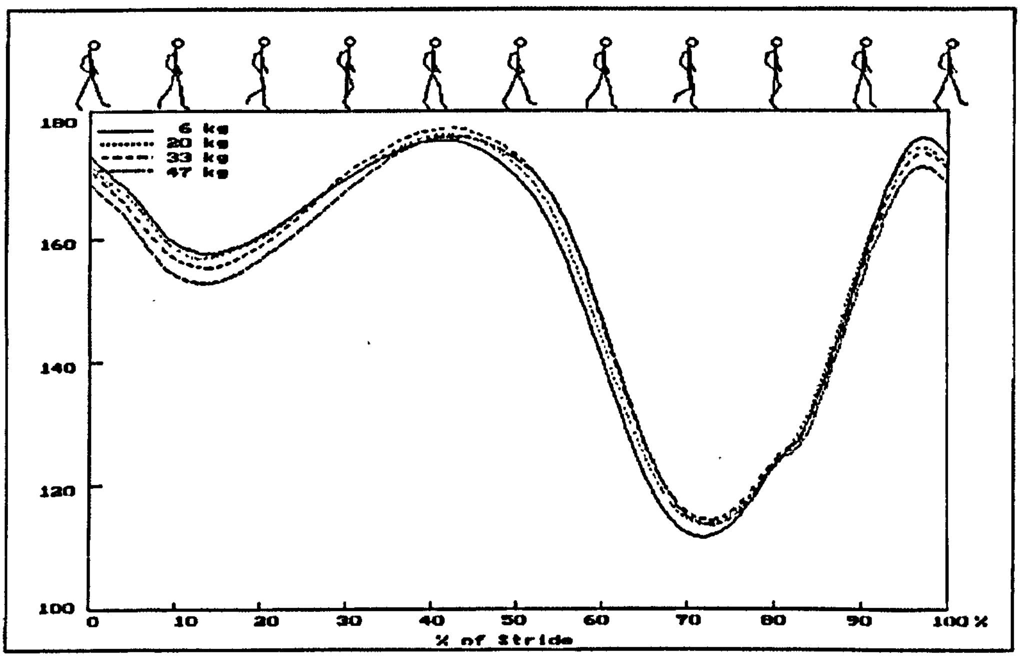


Figure 2.2: Example of sagittal plane knee joint angle (in degrees) against percentage of stride, taken from Harman et al (2000).

Hip Angle

The importance of the hip angle in terms of its effect on injury or changes related to load carriage is limited. Hip angle can be measured in two ways, either the angle between the knee, hip and C7 or the angle of the femur to the horizontal. The former is influenced by trunk angle, thus the greater the forward lean the smaller the angle between the trunk and femur. Changes to the trunk angle are seen as the overriding factor which influence this hip angle, and is therefore of limited clinical use. The second method can be termed the femur angle and is independent of trunk angle, this method was used by Attwells et al (2006). Harman et al (1999 & 2000) and Polcyn et al (2002) all observed a decrease in both maximum and minimum hip angle with load carriage. This is consistent with greater forward lean, as these studies measured hip angle against the trunk. Harman et al, (2000) acknowledge that hip angle changes are due to the 'greater trunk inclination that accompanies load increases'. LaFiandra et al (2003) also observed a increase in hip excursion when carrying a load of 40% bodyweight. Attwells et al (2006) measured the angle of the femur relative to the vertical, this negated the effect of the trunk. This study found a significant increase in femur angle RoM during stance as load was added. Analysis of the data showed that the increased RoM was primarily as a result of a reduced minimum angle, or a less vertical femur just before toe-off.

Ankle Angle

To generalise, the ankle angle rarely shows the significant differences or strong relationships with load compared to both the knee and hip angles. This may be due to its relatively stable nature as a joint, or the comparatively small RoM during normal unencumbered walking. With military testing in particular the ankle angle may be restricted further by the wearing military boots which lace-up above the ankle. No differences to the minimum, maximum or RoM of the ankle angle was observed with the following studies (Harman et al, 2000; Attwells et al, 2006). Figure 2.3 shows an example of the typical ankle angle trace plotted against percentage of stride with loads of up to 47 kg, taken from Harman et al (2000).

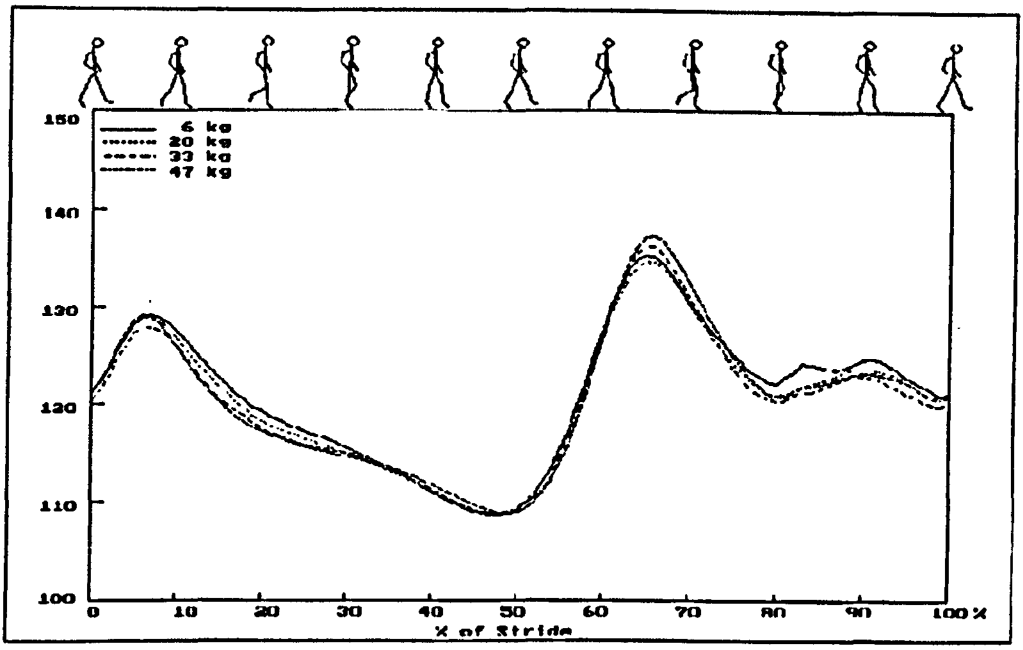


Figure 2.3: Example of sagittal plane ankle joint angle (in degrees) against percentage of stride, taken from Harman et al (2000).

Polcyn et al (2002) did however find an increase in the RoM at the ankle with increasing load. This increases was facilitated by significant decreases in the minimum angle (or greater planterflexion) and increases in the maximum angle (or greater dorsiflexion). As they found with the knee angle, ankle RoM increased by about 0.01 degrees for every 1 N of load carried. The only other study to find significant differences regarding the ankle angle was conducted by Kinoshita in 1985. The principal difference with this study compared to others is that ankle angle during different phases of single support were measured. The majority of studies measured ankle RoM over the entire stride, this may be why few significant difference with load carriage have been observed. Kinoshita (1985) noted increased dorsiflexion in the early mid-support phase (impact peak to force minimum) as load increased. This resulted in the foot being 'rotated anteroposteriorly around the distal end of the metatarsal bones for a longer period of time when the heavier load was carried.' This was suggested to expose the metatarsal bones to greater mechanical stress for prolonged periods of time. It has also been noted that greater dorsiflexion of the ankle is needed to assist knee flexion, and aid the smooth transfer of the system weight in the forward direction during the early mid-stance of gait (Kinoshita, 1985). This suggests that knee bend aids absorption of impact forces by the body, but this in turn places the foot at an increased risk of stress fractures.

Other Measures

The position of the body's CoM during the gait cycle is very important when assessing the biomechanical effects of load carriage. Load carriage will usually result in a displacement of the CoM, and the degree of this displacement has been linked to both a change in physiological and biomechanical parameters. The analysis of the position of the CoM during the gait cycle is usually restricted to its vertical position and subsequent changes associated with additional load. The measurement of the body's CoM with respect to changes in load distribution, load carriage methods or just load itself is calculated with the participant in a static position, usually standing with load carriage system (LCS) donned.

Findings regarding the vertical displacement of the CoM with load carriage show fairly consistent results. As load is added to the body, both the maximum and minimum height of the CoM decrease (Harman et al, 1999 & 2000; Polcyn et al, 2002). This is as would be expected as forward lean and increased knee bend also occur with the addition of load. Therefore, it may be more interesting if changes to the observed RoM of the CoM were observed. However, this is not the case as no significant differences or consistent trends are observed with the RoM (Harman et al, 1999; Polcyn et al, 2002).

LaFiandra et al (2003) investigated the effect of load carriage and walking speed on trunk coordination and stride parameters. They found that load carriage induced decreases in transverse plane kinematics, which included the measurement of pelvis, thoracic and trunk rotations. This is implying that the mid-section of the body (the trunk and hips) is rotating less as greater loads are carried. This in turn may result in a decreased stride length by reducing the angular momentum of the lower body (LaFiandra et al, 2003). Also, a decrease in pelvic rotation may lead to a reduced horizontal excursion of the pelvis, thus shortening stride length. LaFiandra et al (2003) then suggested that in order to maintain the fixed walking speed an increase in hip excursion was observed. However, this did not fully compensate for the decrease in stride length caused by decreased pelvic rotation, so an increase in stride frequency was required.

An angle that may be of interest to military researchers which has received little attention in the published literature is the angle of tilt of the pelvis. This may be of interest because of its potential link to trunk angle. Trunk angle is the principal parameter of interest due to its implications on overuse injuries of the lower back. When trunk angle cannot be measured, due to biomechanical equipment limitations or interference of the load carriage equipment with the C7 or shoulder (the typical regions used to measure trunk angle), the tilt of the pelvis may be used to give an indication of forward lean. A study by Smith et al (2006) investigated the effect of carrying a backpack on pelvis tilt, rotation and obliquity in female college students. The study used an unframed school style backpack loaded with 15% of participant's bodyweight (approximately 6 kg). The effect of carrying the backpack over one or two shoulders was tested against a control condition. Results showed that the angular position of pelvis tilt when carrying load in a backpack supported by both shoulders was greater compared to the other two conditions, the RoM was not affected. They suggest that the clinical implications of this are that forward lean of the trunk may lead to increased lordosis resulting in compression of the lumbar vertebral bodies and facet joints, increased interdiscal pressure and the narrowing of the intervertebral foramina which can result in chronic lumbar pain disorders. Also seen was a decrease in the RoM in pelvis obliquity and rotation when a backpack was carried by either method. Filaire et al (2000) examined the mode of load carriage on the static posture of the pelvic girdle and spine. Carrying 16 kg in a backpack resulted in significantly greater forward tilt of the pelvis compared to all the other methods of load carriage. Neither of these two studies utilised military LCS and the loads carried were relatively small; however, clear significant differences were observed. The relationship or correlation between forward lean and pelvis angle has not been substantiated and will require further research, but in principal pelvis tilt could be used to assess forward lean as a result of load carriage.

Angles of the upper body can also be measured these may include elbow, shoulder and position of the head and neck. Only one study, to the author's knowledge, has been concerned with the measurement of the shoulder and elbow angle, this was conducted by Harman et al (2000). Results showed a significant decrease in maximum elbow angle and increase in minimum shoulder angle with greater load. Harman and colleagues put forward no reason for this change. One possible explanation for this would be a decrease in rearward arm swing. The study did not state if a rifle was carried, so it is assumed that one was not. Rifle carriage will restrict natural arm swing patterns independently of load carriage, therefore shoulder and elbow angle may be of little use when assessing military load carriage.

The position of the head on the neck (or craniovertebral angle) is of interest. It is well established that load carriage causes forward lean of the trunk, but the position of the head has not been as thoroughly researched. The interest here lies with the resulting strain caused by the forced extension of the neck needed to keep the head looking forward and not at the ground. This has been associated with musculoskeletal dysfunction, head and neck aches and shoulder pain (Raine and Twomey, 1997). In terms of this angle in the load carriage literature, Chansirinukor et al (2001) showed that a load of 15% of bodyweight carried in a backpack by school children caused a more forward head posture. Attwells et al (2006) showed with military load carriage a decrease in craniovertebral angle, or more forward head posture, was observed. The load carrier either has a choice to keep their head facing toward the ground just in front of them, or place the musculature of the neck under addition stress and extend the neck to keep the head facing forward. In a lab based trial the need to keep the head up and looking a way in front of the body is not as essential as the terrain is consistent and threat low. This however will not be the case with military personnel on operations as the head will have to be looking well in front for potential dangers.

2.2.3 Spatiotemporal Parameters

The effect of load carriage on spatiotemporal parameters, such as stride length, time and frequency, double and single support, swing time and walking velocity (figure 2.4), is the subject of mixed conclusions within the literature. These parameters have been shown to be very inconsistent especially when considering free verses fixed walking speeds, and military trained verses untrained participants. During biomechanical studies it is conventional to fixed walking speeds. This is as increased walking speeds changes joint kinematics (Harman et al, 2000b), increase GRF (Munro et al, 1987; Nilsson and Thorstensson, 1989; Keller et al, 1996; Harman et al, 2000b; Hsiang and Chang, 2002) and alter both stride length and frequency (Cavanagh and Kram, 1990). All these parameters are of interest to the current thesis and not controlling for speed would make conclusions as a result of load carriage difficult. There is a fair amount of literature available regarding the spatiotemporal effects of load carriage, this will be reviewed below.

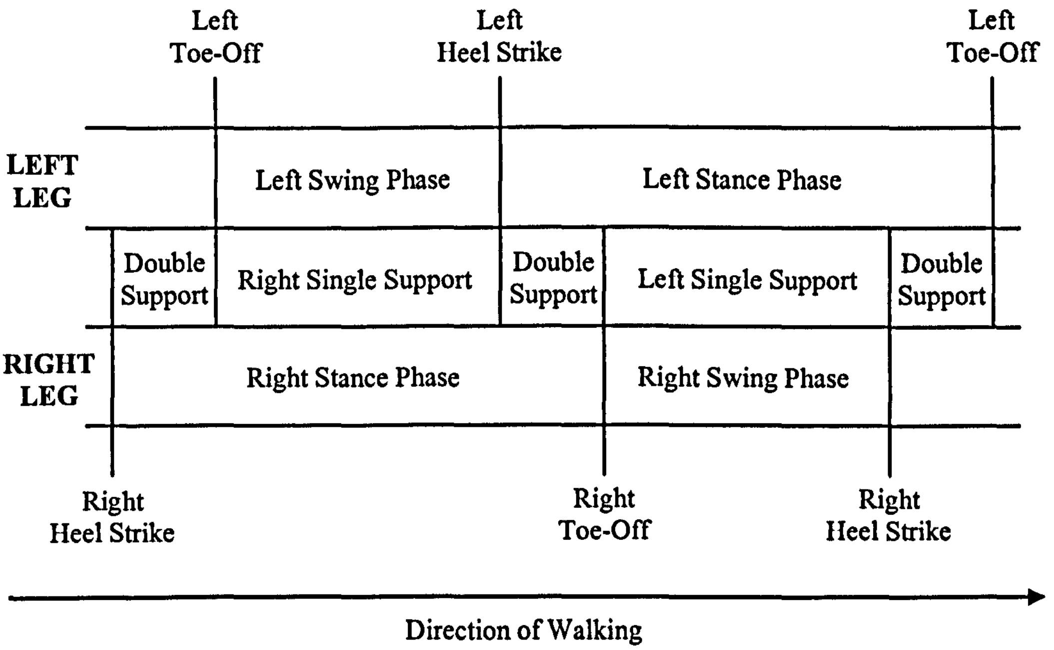


Figure 2.4: Timings and identification of spatiotemporal parameters from the gait cycle.

Within the literature the only parameter that has been shown to change constantly is double support, this is when both feet are in contact with the ground. An increase in carried load induces an increase in double support (Ghori and Luckwill, 1985; Kinoshita, 1985; Martin and Nelson, 1986; Wiese-Bjornstal and Dufek, 1991; Harman et al, 1992; Harman et al, 2000; Polcyn et al, 2002). Polcyn et al (2002) suggest that increasing the time spent with both feet in contact with the ground decreases the internal load on the joints of the lower extremity. They also estimate the increase in percentage of the stride spent in double support to increase by less than 0.01% for each Newton of load added.

During fixed speed walking trials changes to stride length and frequency with additional carried load are important. It has been suggested that at a fixed walking speed during load carriage causes a decrease stride length and subsequent increase in stride frequency. Only studies by LaFiandra et al in 2002 and 2003 found this to be true, they attributed this change to a decrease in pelvic rotation when load is carried. However, the same trend again observed by Martin and Nelson (1986). Harman et al (2000) found significant increases in stride frequency but no significant changes to stride length with load. Vacheron et al (1999) observed that stride frequency increased almost linearly as load increased; however, this was only with expert and occasional hikers. Novice hikers changed there stride frequency very little. The inverse was seen with stride length, more experienced hikers shortened their stride lengths and novice hikers again did not. Harman et al (1992) found changes to both stride length and frequency to be insignificant when carrying increasing load. Polcyn et al (2002) found inconsistent changes to stride frequency with load carried in a variety of LCS. Other studies to observe non-significant changes to stride length with greater loads were Kinoshita (1985) and Obusek et al (1997). As can be seen from the studies above there are no definitive changes to stride length and stride frequency with load. Studies investigating the effect of asymmetric manual load carriage (the carriage of load in one hand) have also shown a decrease in stride length and increase in stride frequency, when carrying loads of between 10 and 20% of bodyweight (Crosbie et al, 1994; Crowe and Samson, 1997)

One of the parameters that are not reported very frequently in the published literature is stance (aka single support) time. Kinoshita (1985) reported a significant increase in stance time when carrying a load of 40% bodyweight in a backpack compared to a no load condition. There was also a trend for an increase at 20% bodyweight. A significant increase in stance time was also observed by Wiese-Bjornstal and Dufek (1991) when loads of 25 and 40% bodyweight were carried in a backpack. Martin and Nelson (1986) found inconsistent changes to stance time with increases at the heavier loads compared to the lighter loads, and decreases with the lighter loads compared to the control condition. Another stride parameter that shows a relatively consistent pattern of change with added load is the percentage of the stride spent in either swing or stance phase. An increase in load has been shown to either decrease the swing percentage (Gory and Luckwill, 1985; Martin and Nelson, 1986) or increase stance (Harman et al, 1992). This has been suggested to aid stability and assist with the even distribution of load and joint forces between the limbs. The final significant differences (reported below) may appear to go against the thought of increase foot-floor contact time in order to increase stability. Both Kinoshita (1985) and Wiese-Bjornstal and Dufek (1991) found significant decreases in percentage of stride spent in single support. This however is most likely a result of the increased double support found with both these, and numerous other, studies.

To the author's knowledge two studies have investigated spatiotemporal parameters during load carriage at a 'free' walking speed. Charteris (1998) found that when participants walked at free speed carrying 20, 30, 40, 50 and 60% BW there were no significant differences in stride length and frequency, or stance and swing time under increasing load. However, there was a tendency (although not significant) for heel only contact time to be reduced. Charteris concludes that some load-based effects on temporal parameters may only become apparent under very heavy loads. The other study was conducted by Attwells et al (2006) who observed a significant increase in walking speed from the no load to 8 kg condition. Walking speed then decreased as loads of up to 42 kg were added; however, it did not return to its no load value. The increase in speed with the 8 kg condition was achieved by an increase in both stride length and stride frequency. Interestingly stance time remained relatively constant, at between 0.58 and 0.62 seconds for all conditions. Other parameters such as double support and swing time were not measured with this study.

2.2.4 Kinematic and Load Carriage Summary

Trunk angle is the principal kinematic parameter of load carriage. It is well established that increasing load carriage causes an increase in forward lean. Forward lean is induced to balance out the moments produced by placing load on the back. This may however put the musculoskeletal structures of the back under increased risk of injury. Knee angle shows some interesting alterations with load carriage, namely an increase in knee flexion just after heel strike in order to aid the absorption of impact forces. Over the entire stride however a decrease in knee angle RoM is observed. Hip and ankle angles differ little with load carriage and are considered to be of comparatively little consequence. The vertical position of the CoM decreases with load carriage, this is induced by forward lean and greater knee flexion. This is in an attempt to maintain stability during load carriage. Load carriage also induces a more forward head posture, which has been suggested to increase the risk of injury to the head, neck and shoulders.

To summarise succinctly the spatiotemporal effects of load carriage is difficult. The most commonly observed and well established change to stride is an increase in double support with added load. Other factors which have been suggested by some authors but not found by others are a decrease in stride length, and subsequent increase in stride frequency to maintain walking speed. A decrease in swing time has also been observed, but changes to stance time are inconsistent. The use of a fixed walking speed is ideal as speed is the principal mechanism behind many changes to stride parameters. Also, when considering military personnel a fixed walking speed is a training effect that aids their marching as a unit.

2.3 Effects of Load Carriage on the GRFs of Gait

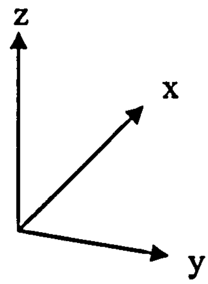
2.3.1 Introduction

The second branch of biomechanics is kinetics; this examines the forces that act on a system, such as the human body. Kinetics attempt to define the forces that cause movement. Kinetics can be broken down further into 2 subcategories, linear and angular kinetics. The linear kinetics of interest to this thesis are the analysis of ground reaction forces (GRF), these will be described in detail in section 2.3.2. Angular kinetics are concerned with forces that result in a rotation or turning of an object or system. This thesis is concerned with the moments that act on joints of the body, this will be discussed in section 2.5.

This next section of the literature review will outline the nature of GRF, how they are measured and their importance in gait analysis. After this the effect of load carriage on GRF parameters will be assessed. The literature review will focus on the research that has been conducted to date; with methodologies, major results and relevant conclusions discussed.

2.3.2 Ground Reaction Forces

GRFs are forces, measured in Newton's, that are exerted on the walking surface during the gait cycle. They reflect the acceleration patterns of the body's centre of mass (CoM) (Munro et al, 1987). The forces that are generated are in accordance with Newton's 3rd Law of Motion, this sates that every action has an equal and an opposite reaction. GRFs occur in 3 common axes, as the foot strikes the floor a reaction occurs in these 3 axes simultaneously. Figure 2.5 illustrates the direction of the forces.



Force	Direction	Description
y	Mediolateral	Side to Side
x	Anteroposterior	Braking & Propulsive
z	Vertical	Main GRF

Figure 2.5: Summaries the forces and axes that each component acts along.

Each of these 3 forces produces its own pattern of reaction. These patterns can be displayed as vector diagrams, showing both the magnitude and direction of the force; or more commonly in the form of a GRF-Time history, these show the forces produced plotted against time. Figure 2.6 shows a typical GRF-Time history produced during normal human walking.

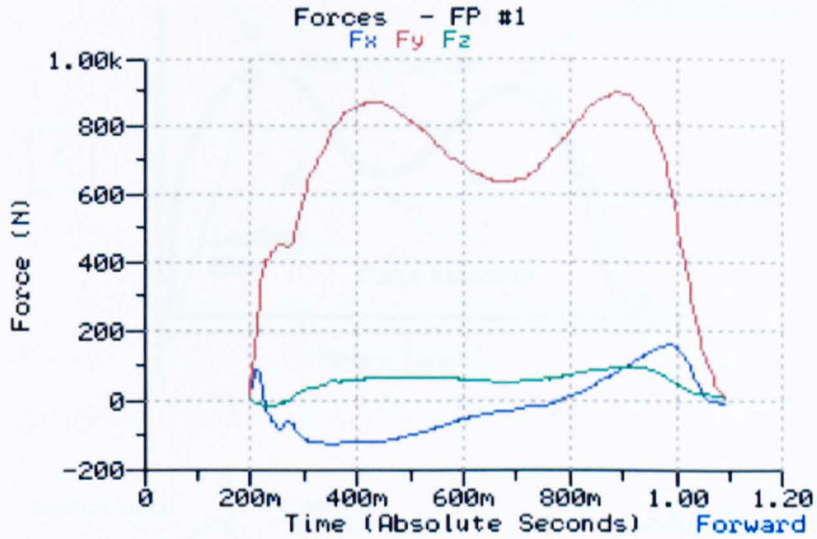


Figure 2.6: Typical GRF-time history during walking, taken from Kistler 9286A force plate technical information PDF.

GRFs have been shown to demonstrate greater sensitivity to changes in gait than computed joint kinematics (Winter, 1987). Physiological studies suggest that a load of 30% of bodyweight (BW) can be carried with ease by healthy individuals, with few adaptations in physiological parameters. Whereas loads of as little as 20% BW produce substantially modified gait patterns compared to no load conditions (Kinoshita, 1985). This illustrates that the study of GRFs produce a relevant and perceptive insight into changes in gait patterns with the addition of load, allowing even the most subtle and sensitive differences to be observed and studied. The study of GRFs during walking can provide relevant information about the mechanisms of gait and provides a measure of the impact force on the foot, and is therefore essential in the understanding and prevention of lower extremity injuries (Harman et al, 2000).

There are many definitions used in the literature for the different parameters of GRFs, Figure 2.7 shows the definitions that will be referred to throughout the literature review. The figure defines the most important and frequently used GRF parameters, but not all of the parameters that may be studied. Also not included are times to certain events, e.g. time to impact peak, these are equally as important in the analysis of GRFs. Section 3.6.1 of the methodology will highlight in further detail which parameters will be of interest to the experimental studies, also defining how they were calculated.

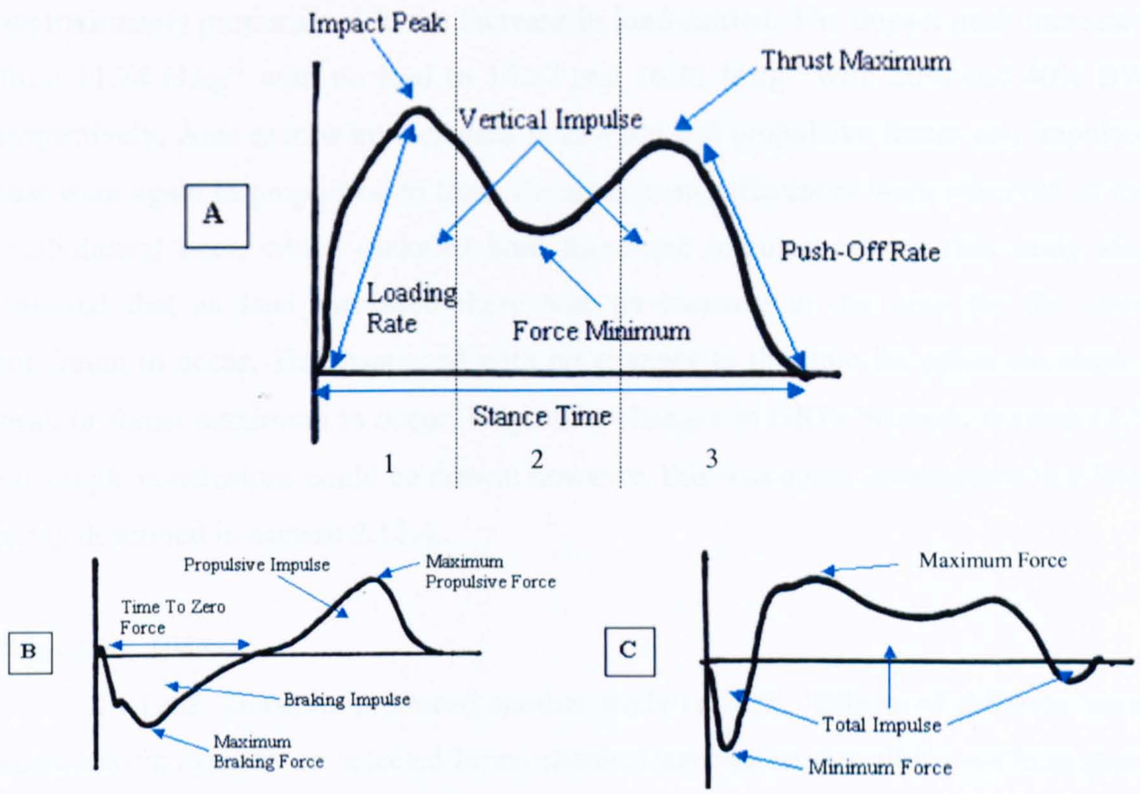


Figure 2.7: Graphical representation of selected GRF parameters. A) Vertical, B) Anteroposterior, C) Mediolateral. Adapted from Kinoshita and Bates (1983). Graph A section 1) refers to the heel strike phase of gait; 2) mid-stance and 3) push-off.

2.3.3 The Major Studies

Kinoshita and Bates, 1983

Kinoshita and Bates conducted the first major piece of research regarding GRFs and load carriage in 1983. They studied the effects of two different LCS on GRFs during walking, a standard backpack and a double-pack (with weight evenly distributed between a front and rear pack). 5 males walked over a Kistler force plate sampling at 417 Hz, photoelectric cells placed 4 m apart measured walking speed. Data from 10 successful trials was collected for each of the following conditions: 1) No load. 2) 20% BW carried in backpack. 3) 20% BW carried in the double-pack. 4) 40% BW in backpack. 5) 40% BW in the double-pack. The target speed was between

1.17 and 1.33 ms^{-1}. Force data were normalised by dividing the force produced by the combined mass of the backpack and the participant.

Significant increases in the three main vertical forces (impact peak, force minimum and thrust maximum) and total vertical impulse were found to be approximately proportional to the increase in load carried. The impact peak increased from 11.74 $N.kg^{-1}$ with no load to 14.27 and 16.33 $N.kg^{-1}$ with 20% and 40% BW respectively. Also seen were increases in braking and propulsive forces and impulses that were again in proportion to load. No significant differences were observed in the mediolateral axes, which included both force and impulse values. This study also reported that as load increased there was an increase in the time for the force minimum to occur. This happened with no changes to the time for either the impact peak or thrust maximum to occur. Regarding changes in GRFs between the two LCS no simple conclusions could be drawn; however, this was again investigated in a later study described in section 2.11.4.

Kinoshita, 1985

In 1985 Kinoshita produced another study entitled, 'Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait'. The methods remained the same as the 1983 study except a different 10 males were involved. This study found that as load increased the double support period, expressed as a percentage of total support time, also increased. Conversely, periods of single support experienced a decrease. These changes were seen even though there was no change to the absolute value of stance time. All the measured GRFs parameters increased in proportion to load. Kinoshita (1985) suggests the increases in GRFs are due to the static effect of the load rather than any increases in the acceleration of the body segments. Table 2.1 shows the increase in normalised force produced with the addition of load, (values significant to $p<0.01$). In summary, gait patterns were substantially modified when carrying even the lightest loads, this is despite physiological studies suggesting that a load of 30% BW or less can be carried with little or no effect on gait efficiency.

Table 2.1: Selected force parameters results, taken from Kinoshita (1985).

Load	**Vertical Force Parameters**			
	Impact Peak	Force Min	Thrust Max	Impulse
0	11.66	7.31	10.73	5.78
20% BW	13.88	8.36	13.01	6.96
40% BW	16.08	9.46	14.91	8.06
Load	**Anteroposterior Force Parameters**			
	Max Braking	Max Prop	Braking Imp	Prop Imp
0	2.18	2.18	0.37	0.35
20% BW	2.72	2.7	0.48	0.43
40% BW	3.16	3.21	0.56	0.53

Natick Reports

The vast majority of military research conducted in the United Sates of America is done at the US Army Soldier Systems Centre (aka Natick), located in Natick, Massachusetts. For the past 50 years the centre has been responsible for researching, developing, fielding and managing all aspects of a soldier's equipment from food, clothing, shelters, airdrop systems to soldier support items. Included in the Soldier Systems Centre research remit is biomechanical testing of load carrying equipment. Research conducted is published firstly in Natick reports and then potentially in peer-reviewed journals. The proceeding section of the literature review is concerned with research conducted at Natick and published in such reports.

Harman et al (2000) looked at the effect of backpack weight on the biomechanics of load carriage. They used an experimental design of backpack that was based on the MOLLE US military backpack, and added loads of 6, 20, 33 and 47 kg. Sixteen male participants walked at speeds of 1.17, 1.33 and 1.50 $m.s^{-1}$ while EMG, kinematic and kinetic data were collected. Three trials per load at each speed were attained. Results from the kinetic data showed that all vertical and anteroposterior GRFs and impulses increased proportionally with the first 3 loads. This was however not the case with the heaviest load where the increase was less than previously seen. This suggests a protective adjustment, possibly achieved by increased knee flexion (observed with the 47 kg condition) aiding the damping and absorption of the vertical impact forces. Changes to the mediolateral axes of GRF were not significant. The effect of walking speed during load carriage on gait parameters was published in a different report (Harman et al, 2000b). Criticisms of this study are that only 3 trials were collected at each loading condition, and not the 10 trials as suggested by Hamill and McNiven (1990). No attempt was made to measure the changes in the CoM, so it is unclear if the addition of the load altered this. However, this study has utilised a very extensive range of loads with a top load of 47 kg. This is a substantial load and should be sufficient for any potential changes to be observed, as illustrated by the suggestion of a protective mechanism.

Polcyn et al (2002) produced a very comprehensive study investigating the effects of carried weight on maximal performance, physiology and biomechanics. Numerous different loads and LCS were utilised, between 3 and 18 trials were conducted at a speed of 4.8 $km.h^{-1}$ (or 1.33 $m.s^{-1}$) for each LCS. Amongst the many results were that the impact peak and thrust maximum were positively and highly correlated to total load. This is shown by a proportional increase in the vertical force produced as load was added of almost 1 N for every 1 N of added load. Again they suggest that the increase in GRF is primarily due to a direct effect of the load. The continual exposure to high magnitude vertical forces was stated as a significant risk factor for the development of both acute and chronic overuse injuries. Anteroposterior forces were also highly correlated to total load with approximately a 0.17 N increase in maximum braking and propulsive force for every 1 N added. As one would expect increases were seen in the GRF parameters mentioned above with the addition of load. Increases were also observed in vertical and anteroposterior impulses, and mean GRF produced over the entire gait cycle. Reinforcing knowledge from previous literature, mediolateral forces showed no significant difference with added load, but did show a trend for an increase. This study was conducted to assess the potential differences between different LCS at increasing loads. It does not attempt to explain any potential mechanisms for these observed changes, but it does support existing literature.

Wiese-Bjornstal and Dufek, (1991)

Wiese-Bjornstal and Dufek, (1991) investigated the effects of 25 and 40% BW loads carried in an external frame backpack. Eight experienced backpackers completed 10 trials at a fixed speed with each load, the force generated was normalised to a system mass (subject + footwear + load). A surprising result was that the relative impact peak was highest for the no-load condition, this is in direct contrast with other findings. We would expect to see no change within this normalised data, as this would indicate a proportional increase. This in turn suggests that a protective mechanism is activated to minimise the impact force produced. The authors suggest that the decrease in normalised force with increasing load carriage may have been a result more weight being shared between the limbs during the longer double support phase. Also seen was a significant increase in stance time with added load.

2.3.4 Manual Load Carriage

The effects of load carriage are also very important in industry and within the emergency services, with manual lifting and carrying tasks essential. For this reason research has been conducted into side (or asymmetric) load carriage and front (or anterior) load carriage and their effects on GRFs. Bunterngchit (1989) reported a proportional increase in the impact peak and force minimum with loads of up to 250 N being carried in front of the body. They also noted during walking that forces of up to 1.3 times BW pass through the lower extremities. With the addition of load the magnitude of the force that needs to be dissipated by the body will be increased.

Crosbie et al (1994) set out to investigate the effect of side load carriage on the kinematics of gait, using both male and female participants carrying 10 and 20% BW. Their results showed that when a load was carried there was a decrease in stride length, and in an effort to maintain preferred velocity (that was unchanged) cadence was increased. This was statistically significant for both load conditions, with the difference being more apparent in the female participants. Crosbie et al also noted that the body's CoM significantly shifted towards the side of the load and consequential postural adjustments were made. The trunk displacement towards the contralateral side and abduction of the arm not carrying the load was in an effort to counterbalance the effect of the shift in the CoM caused by the asymmetric load.

In 1997 Crowe and Samson looked at the symmetry of gait while carrying a load of 15% BW in the participant's dominant hand. There was an increase in preferred walking speed, decrease in stance time and therefore a resulting increase in cadence. Also found were asymmetries in left and right single support times, with increased support times on the side of the carried load. During steady speed walking the body's CoM undergoes roughly sinusoidal oscillations, a vertical oscillation at twice the frequency of the walking cycle; side load carriage had no effect on these oscillations.

2.3.5 GRF and Load Carriage Summary

Conclusions drawn from the literature confirm, that as would be, expected both vertical and anteroposterior GRFs produced during gait increase when load is applied to the body. This is shown consistently with the vertical parameters of GRFs (including impact peak, force minimum, thrust maximum and vertical impulse) and anteroposterior parameters (braking and propulsive maximums and impulses). However, the proportionality or rate of this increase has been debated within the literature with the majority of research suggesting the increase in vertical and anteroposterior GRFs to be directly proportional to the applied load (Kinoshita and Bates, 1983; Kinoshita, 1985; Holmes et al, 1999; Tilbry-Davis and Hooper, 1999; Lloyd and Cooke, 2000; Polcyn et al, 2001). Other studies conducted suggest that protective mechanisms are activated, such as an increase in double support, decreased walking speed or altered joint kinematics, when carrying heavy loads in an effort to reduce stresses placed on the lower extremities (Wiese-Bjornstal and Dufek, 1991; Harman et al, 2000). Also, changes in the mediolateral axes of GRFs have been found to be insignificant (Kinoshita and Bates, 1983; Lloyd and Cooke, 2000; Harman et al, 2000; Polcyn et al, 2002).

GRFs increase proportionally with walking speed (Munro et al, 1987; Nilsson and Thorstensson, 1989; Keller et al, 1996; Harman et al, 2000b; Hsiang and Chang, 2002). Therefore care must be taken when interpreting results that compare GRFs at 'free speed'. Many of the changes to GRF parameters associated with different LCS are as a direct effect of changes to the body's CoM. Finally, high impact forces, like those experienced during load carriage or running, are major risk factors for overuse injuries (Nigg et al, 1987; Keller et al, 1996; Knapik, 2001). Therefore the analysis of GRFs may aid researchers in understanding the effects that load carriage may have on lower extremity injuries.

Limitations of previous studies conducted in this area are that loads have typically been restricted to 20 and 40% of bodyweight, usually in a backpack alone. Heavy load carriage of up to 40 kg has not been investigated in depth, nor have the effects of rifle carriage and their subsequent changes to GRF parameters. Certain studies have also adopted inadequate methodologies, with insufficient number of repeat trials or not controlling for speed. The majority of the load carriage research has been conducted with either US MOLLE military LCS or using commercial packs. There is little published research that has utilised the LCS of the British Army, namely the '90 Pattern military LCS, or use British military personnel.

2.4 Kinetic Effects of Changing Load Distribution

2.4.1 Introduction

So far this review has been primarily been concerned with load carriage on the posterior of the trunk alone. The distribution of load within a LCS has not been investigated. This section of the literature review will focus on the effects of changing load distribution and its subsequent changes to biomechanical and physiological parameters.

2.4.2 Load Carriage Methods

It has long been suggested that loads should be kept as close to the body's CoM as possible in order for the greatest efficiency and stability to be maintained during human walking (Parkes, 1869; cited from Legg and Mahanty, 1985). It has also been suggested that heavy loads should be supported by larger muscle groups (such as trunk) and not small muscle groups (hands), in order to minimise fatigue or local muscle discomfort (Legg and Mahanty, 1985). For this reason different modes of carrying loads has been the focus of much research, particularly with respect to the physiological cost of load carriage. Physiological studies have shown that loads of up to 20% of bodyweight can be carried on the head by African women with no additional metabolic cost. This 'free ride' may be achieved as no work is done against gravity to raise the carried load with each step (Maloiy et al, 1986). Other studies have focused more on the energy cost of load carried around the trunk as this is more typical in the developed world. In terms of military load carriage, due to significant ergonomic reasons the backpack is the only viable method of load carriage. However, this does not mean that distributing load on the anterior of the trunk or around the hips is not achievable. Or even that backpack design changes such as internal and external frames, hip belts or altering the CoM of the backpack can't have significant physiological or biomechanical effects.

2.4.3 Double Packs

Physiological studies have found varying responses when double-packs (load distributed on the anterior and posterior of the trunk) have been compared to backpacks. Some studies suggest that no significant physiological differences are observed (Winsmann and Goldman, 1976; Legg and Mahanty, 1985; Holewijn, 1990), whereas others have found significant differences (Datta and Ramanathan, 1971; Lloyd and Cooke, 2000; Coombes and Kingswell, 2005). Biomechanical studies have shown that the carriage of load in a double pack results in numerous effects, most commonly seen is a decrease in forward lean (Kinoshita, 1985; Harman et al, 1994; Attwells et al, 2004; Fiolkowski et al, 2006). Hip flexion is also decreased when carrying load in a double-pack compared to backpack (Fiolkowski et al, 2006). Coombes and Kingswell (2005) investigated biomechanical and physiological parameters when running while carrying 8 kg in either M83 assault vest (which distributes load closer to and on the anterior of the body), or conventional webbing, (which uses hip pouches and a yoke). Results showed that energy expenditure was reduced when carrying the M83. This change was attributed to the high correlation of stride length and stride frequency ($r = 0.77$ and 0.89, respectively) with unloaded running compared to running with the M83 webbing. Correlations for the conventional webbing were $r = 0.19$ and 0.17, for stride length and frequency respectively. The study suggests that when load is more evenly distributed around the trunk the body maintains preferred kinematics. Attwells et al (2004) also found kinematic differences when wearing webbing that distributes load more evenly, with vest webbing showing a reduced ankle RoM and minimum knee angle compared to waist webbing.

2.4.4 Load Placement

Load placement within a backpack also alters the parameters of load carriage. This can be changed in terms of both the vertical height and the horizontal distance of the CoM of the pack compared to the body's CoM. Internal and external frame packs change such properties by sitting the pack away from the back with the external frame. Research suggests that there is little difference in energy cost between internal and external frame backpacks (Kirk and Schneider, 1992; Harman et al, 1997). However, differences were observed with internal frame backpacks producing the fastest obstacle course times and external frame packs showed advantages in standing from a prone position (Harman et al, 1997). Keeping the load closer to the body via an internal frame backpack has been shown to reduce the trunk angle (or forward lean) and trunk angle RoM compared to carrying load in an external framed backpack. Other biomechanical changes observed were a greater impact peak and RoM at the hip (Frykman et al, 2004).

The vertical placement of load has also been shown to alter both biomechanical and physiological variables. Studies have shown that load placed high in the pack significantly decreases energy cost compared to when carrying it in a low position (Obusek et al, 1997; Law et al, 2005). However it is not solely beneficial to carrying load as high up as possible. Holewijn and Lotens (1992) showed a decease in mobility performance when load was carried high on the back, this was suggested to lead to a slower deceleration and acceleration of the upper body. The same factor may also result in a decrease in stability when walking, particularly over unstable or uneven terrain, as it results in higher moments of inertia when the feet are taken as the axis of rotation (Bloom and Woodhull-McNeal, 1987). These effects are cumulative when an already taller individual is considered (Hellebrandt et al, 1944). A study by Bloom and Woodhull-McNeal (1987) examined the postural adjustments while standing with two types of packs. These packs were an internal frame back with a low CoM and an external frame pack with high CoM. Looking at the picture supplied the CoM of the pack was the dominate factor. Results from the study showed that the lower CoM with the internal framed pack requires more compensation by the body and results in more forward lean. This was as a result of the necessity to balance the moments around the hips (Bloom and Woodhull-McNeal, 1987). Another study by Bobet and Norman (1984) highlighted that load placed high on the back resulted in significantly higher levels of muscle activity of the erector spinae and upper trapezius muscles, while displaying no significant change in heart rate between the methods. As always with load carriage a trade off is needed and a compromise in CoM placement reached.

2.4.5 Load Distribution and the Kinetics of Gait

More specific to the current thesis is the effect that load distribution has on the kinetics of gait, in particular with respect to GRF. A hand full of studies have investigated the effects of shifting load distributions between backpacks, front-packs, double-packs, military LCS and manual load carriage.

Kinoshita, 1985

Again we start with the work of Kinoshita (1985) who used a backpack and double-pack weighted to 20 and 40% of bodyweight to assess changes in GRF parameters. Results showed that the carrying load in the double pack lead to an increase in the force minimum and decreased maximum braking force compared to the backpack conditions. Also, the double-pack significantly reduced forward lean and brought stance times more in-line with the no-load condition. These differences were attributed to the more erect posture maintained when walking with the double-pack. More vertically orientated force vectors were suggested to be produced compared to the incline posture induced with the use of the backpack. Other significant differences were also observed with the time parameters of gait. The time for peak forces in the anteroposterior axis and vertical force minimum occurred later on in the gait cycle for the double-pack condition. Kinoshita suggests that this may also be a result of the difference in posture with the two systems, and states that 'The inclined posture accompanying the backpack system appeared to facilitate forward advancement of the body, while erect posture associated with the double-pack system appear to inhibit this advancement.'

Lloyd and Cooke, 2000

In 2000 Lloyd and Cooke proposed a study that aimed to investigate the changes in kinetics from unloaded walking to carrying a load of 25.6 kg in either a traditional backpack or a new backpack design that incorporates front balance pockets (AARN), both packs had a 65 litre capacity. Four male and 5 female participants completed 3 successful trials, walking over a Kistler force plate at a target speed of between 2.95 and 3.05 $km.h^{-1}$. The absolute force values were then normalised to BW and time scales were expressed as a percentage of stance time. All 3 axes of force were analysed but they only presented the vertical and anteroposterior data as the mediolateral force provided no useful or significant information.

Results for the vertical GRFs show that the normalised impact peak increased from 9.98 (unloaded) to 13.20 (AARN) and 13.27 $N.kg^{-1}$ (traditional). Anteroposterior force also increased with load in a similar manner. Comparing the two types of pack the traditional pack showed a trend ($p=0.058$) for slightly longer stance times than the AARN pack. Interestingly, the AARN pack produced significantly smaller increases in propulsive force than the traditional pack (-0.79 compared to –0.94 $N.kg^{-1}$). Lloyd and Cooke hypothesise that this may be due to the differences in forward lean, and therefore changes in the CoM. Forward lean for the AARN pack was significantly less than with the traditional pack, this effects the momentum of the upper body and hence reduces the need for such a large propulsive force. Care must be taken when interpreting these results as only 3 trials for each condition were collected, with Hamill and McNiven (1990) suggesting that at least 10 trials are necessary to form a reliable and stable mean. Therefore it is possible that the differences observed are to some extent an artefact of an unstable mean. Also, only one loading condition was utilised so comparisons between different loads were not possible.

Harman et al, 2001

Harman and colleagues produced another study investigating the effects of backpack volume on various biomechanical parameters at a walking speed of 1.32 $m.s^{-1}$. Two prototype packs were used for this study. They were the MOLLE standard and extended (prototype standard issue pack for US army, replacing the ALICE pack) and the SPEAR (a pack designed specifically for the Special Forces). The masses of the packs were approximately the same at 20 kg (± 1 kg), but the dimensions and volumes were different (see Table 2).

Table 2.2: Pack dimensions, volume and weight of the 3 different packs used in Harman et al (2001).

		Pack System	
Measurement (cm)	MOLLE St	MOLLE Ex	SPEAR
Height	84.5	87.0	94.0
Width	41.0	65.5	59.0
Depth	32.0	54.5	28.5
COM above belt	21.6	25.3	20.6
COM behind back	6.1	11.2	-3.8
Volume (l)	40.6	108.6	154.1
Carried Load (kg)	20.4	20.6	21.1

Results showed that the MOLLE standard pack increased maximum braking force compared to the other packs, (-0.209 $N.kg^{-1}$ with the MOLLE standard compared to -0.201 and -0.198 $N.kg^{-1}$ for the MOLLE extended and SPEAR packs respectively). This may be due to the increase in stride length that was observed. As the foot is placed further in front of the body's CoM this generates larger braking forces. Also, the force minimum was lower for the MOLLE than the SPEAR. Harman et al suggest that the above significant differences in force parameters were attributed to the changes in the CoM of the system and the impedance in arm swing. This study can quantitatively compare the changes to the GRFs between the LCS with respects to the changes to the CoM, as both these parameters were measured, and show definitive changes in GRFs as a result of the changes to the CoM.

Hsiang and Chang, 2002

Hsiang and Chang (2002) also investigated the effects of different methods of load carriage on GRFs, 15 male participants walked at 1.07, 1.43 and 1.78 $m.s^{-1}$ with no load, backpack, front-pack, double-pack or carrying the load with both hands in front of the body. The load in the 4 conditions was 13.61 kg, and data were collected for 5 trials. Results showed an increase in the impact peak, thrust maximum and force minimum with the carried loads compared to no-load. Hsiang and Chang found that the two-hand carrying and front-pack condition produced significantly higher impact peaks than the other loading conditions. This may be due to a forward shift in the body's CoM thus creating more forward and downward force as the body begins to roll over the heel at heel strike, generating a greater reaction to the force. Conversely, lower thrust maximums were observed as active momentum had been generated by the increased force at impact, in accordance with the inverse pendulum model as proposed by (MacKinnon and Winter, 1993). Their results for loading rate and push-off rate showed increases in both with the addition of load, and an affect depending on which loading condition was employed. The double-pack produced the lowest loading rates (or a less steep gradient), whereas the greatest push-off rate was seen with the double-pack and two-handed carrying. Results also showed an increase in all of the measured GRF parameters with an increase in walking speed. No mechanisms were proposed for the changes to the push-off and loading rates or even attempts to classify any effects that these increases may cause. Changes to the body's CoM were the proposed mechanism for the differences observed between the LCS, however this data were not presented. Again only 5 trials were completed for each condition, and only one loading condition adopted.

Koulmann, 2006

A load of 35% of bodyweight was carried in either a double-pack (1/3 carried on the front of the trunk, 2/3 on the back), traditional backpack or backpack permitting back aeration. Participants walked for 2 hours on a treadmill at a speed of 45% of VO_{2max}. Numerous biomechanical, physiological and thermoregulatory responses were measured, including vertical and anteroposterior GRF. No significant differences were observed with any of the kinetic parameters measured during this study as a result of changing the load distribution.

2.4.6 Load Distribution Summary

Placing load closer to the body's CoM, usually by evenly distributing load around the trunk, is biomechanically and physiologically more favourable. Most commonly seen are a more upright walking posture, decrease energy cost, reduced stance time and a decease in maximum braking force, while an increased force minimum is also observed with the distribution of load around the trunk. Shifting the placement of load either vertically or horizontally also has significant physiological and ergonomic effects. As always with load carriage a trade-off is needed and a compromised reached in the optimal placement of the CoM within a LCS.

2.5 Effect of Load Carriage on Joint Powers and Moments

2.5.1 Introduction

As mentioned previously kinetic data can be split into two branches, linear and angular. This section of the literature review will discuss angular kinetics and in particular joint moments. Then the pertinent literature will be reviewed, this may be limited as only few studies have directly investigated the effect of load carriage on joint powers and moments. To the author's knowledge no study has looked at the effect of joint forces in all 3 planes of movement. The analysis of joint moments in the sagittal plane of flexion and extension are most common, even then with respect to load carriage this only includes relatively few studies.

2.5.2 Kinetic Data

Inverse dynamics can be used to predict accurately the kinetic properties that act on joints. This approach does not measure the reaction forces directly but instead uses the acceleration of the object, in this case the segments of the lower limb. Inverse dynamics calculations can be done manually or by gait analysis packages. Polcyn et al (2002) stated that 'GRF mirror the forces exerted by the ground on the foot during the gait cycle, but do not reveal the magnitude of forces within the skeleton during ground contact.' Studies that use inverse dynamics to calculate joint forces can either examine the moments (aka torque), power or joint reaction forces. This thesis is concerned with the former two, joint moments and power. Inverse dynamics can be performed on either the lower limb (including ankle, knee and hip) or on the whole body. More commonly it is performed on the lower limb, with respect to the load carriage literature, (Harman et al, 1992; Han et al, 1992a and b; Quesada et al, 1996; Harman et al, 2000; Polcyn et al, 2002). However, one study has completed whole body inverse dynamics while carrying loads (Ren et al, 2005). The purpose of this study was to provide data for a gait model, hence kinetic data from the human participants has not been published in the paper. Again, this thesis will concentrate on lower limb kinetics.

2.5.3 Force at the Shoulders and Back

Other studies have been conducted to examine the forces that act on the shoulders when a load is carried. To calculate this, force transducers can be placed at where either the shoulder straps or hip belt is connected to the backpack. Vacheron et al (1999) placed force transducers at either end of the shoulder straps. This study showed that as load carried in the backpack increased the force measured by the transducers increased. At 12.5 kg of carried load the total force measured by the transducers was greater than the load. Also of interest to this study was the potential effect that load carriage experience would have on the force measured at the shoulder straps. At 17.5 kg of carried load novice hikers induced a force that was 5% greater than the load on the shoulder straps, occasional hikers showed values similar to the load and experienced hikers a 2% decrease. Vacheron and colleagues suggested that experienced hikers adapted their posture to the load, whereas the other participants did not adjust so readily.

A study by LaFiandra and Harman (2004) investigated the distribution of forces between the upper and lower back during load carriage. To assess this force transducers were placed at the hip belt-backpack interface. The backpack used was a modified MOLLE US Army military backpack, load of 13.6, 27.2 and 40.8 kg were carried. Results showed that regardless of backpack load the lower back supported approximately 30% of the weight with the remaining 70% supported by the upper back and shoulders. Also found was that vertical forces exerted on the upper and lower back increased proportionally to the mass of the backpack. LaFiandra and Harman (2004) conclude that the use of an external frame backpack with hip belt transfers approximately 30% of the vertical force generated by the backpack to the lower back. This may help alleviate pressure placed on the shoulders and potentially reduce the risk of rucksack palsy.

Work conducted by Jones et al (2005) aimed at developing a methodology to calculate shear forces at the shoulders as caused by load carriage. Strain gauges and accelerometers were used to infer shear forces acting on the shoulders. Three conditions were used in which a '90 Pattern Bergen loaded with 36.4 kg was carried, these were: static, weapon and walking. Both methods were shown to be sensitive to changes in strap loading during the conditions, and showed highly significant increases in shear measures during the walking condition. Also seen was an increase in shear force when the forced posture of rifle carriage was adopted (Jones et al, 2005), thus highlighting the importance of making all LCS assessments whilst a weapon is held or carried.

2.5.4 Effect of Load Carriage on Joint Kinetics

Throughout this literature review no published papers in peer-reviewed journals were discovered regarding the effects of load carriage on joint kinetics. Some research was found but this was in the form of US military technical reports and abstracts from conferences. Despite this, the work was still conducted by established military researchers at the Natick Soldier Systems Center and other institutes. The following section will review these papers.

Han et al (1992a) investigated the effects of various backpack loads on lower body joint torques. Sixteen participants carried loads of 6, 20 and 47 kg in a backpack. Results showed that torques produced at the ankle, knee and hip increased with load over most of the stride. A significant increase in peak torque of the ankle and knee was also observed, the increase at the hip fell just short of significance. Body-plus-pack mass increased by 49%, this was reflected by an increase in the peak ankle torque of 37%. The increase at the knee and hip was much greater at 104% and 107%, respectively. The timing of the peak torque values was not affected by load. They conclude that the burden of carrying heavier loads appears to fall more upon the muscles that generate torque about the hip and knee than the ankle.

Harman et al (1992) looked at the effects on gait timing, kinetics and muscle activity as a result of load carriage. Again a backpack was carried with loads of 6, 20, 30 and 47 kg. Among the results was a significant increase in peak anti-clockwise torque. At the same conference the effects of walking speed while carrying a 20 kg backpack was presented by Han et al (1992b). Results showed that the leg muscles are called upon most heavily to increase load carriage speed, this was reflected in an increase peak anti-clockwise torque.

Quesada et al (1996) conducted a kinetic assessment of marching while wearing military style backpacks, the aim of the study was to better understand the biomechanical effects of marching with loaded backpacks. Loads of 15% and 30% of bodyweight were carried in an ALICE pack and walking speed was fixed at 6 km.h. Kinematic and kinetic data were recorded and from these joint moments (aka torque) were calculated. Results showed that maximum sagittal joint moments increased with load. The peak flexion moments at the knee increased by 82% and 151% with the load of 15% and 30% bodyweight, respectively; while peak ankle dorsiflexion moments rose by 14% and 28%. Quesada et al (1996) end by suggesting that the considerably greater knee flexion moments imply that military recruits exhibit substantial compensations during marching to accommodate their backpack loading. This may contribute to the development of overuse injuries. It was further speculated that increased joint moments may be a compensatory mechanism to effect energy dissipation over a greater RoM. However, this in-turn may reduce acute injury risk but accentuate the risk of long term overuse injuries.

Harman et al (2000) produced a technical report entitled 'The effects of backpack weight on the biomechanics of load carriage'. Included in this report was the torque produced at the ankle, knee and hip in the sagittal plane during load carriage of 6, 20, 33 and 47 kg. Load had the main effect to increase all the torque parameters with the exception of peak ankle dorsiflexion and peak knee flexion torque. As well as the main effect of load many significant post-hoc differences were observed particularly at the extreme loads. As body-plus-pack mass increased by 49% ankle peak planterflexion torque increased by 38%, knee peak extension torque increased by 98% and finally hip peak extension torque by 47%. These results show that while the ankle torques increased by less then expected from the change in load and the hip increased proportionally to the load. Knee extension torque was seen to increase by twice that expected from the change in load alone. This indicates that the quadriceps muscles assume a disproportionate share of the burden during heavy load carriage, while the calf muscles assume less than expected.

Polcyn et al (2002) measured joint reaction forces and not joint moments (or torque). They found that joint reaction forces increased significantly as additional load was carried. However, key differences were observed with joint forces compared to joint moments. Forces at the proximal joints (hip) increased at a less rapid rate compared to distal joints (foot). This indicated the attenuation of forces when transmitted from the ground up through the leg. Linear regression revealed that peak joint reaction forces for all three joints increased by almost 1 N for every 1 N increase in carried load. Polcyn and colleagues conclude that the risk of injury to joints increases steadily as the load the soldier carries increases.

2.5.5 Power and Moments Summary

All studies that detail the effect of load carriage on joint moments (aka torque) show an increase in moments as load increase (Harman et al, 1992; Han et al, 1992a; Quesada et al, 1996; Harman et al, 2000). These studies have also only investigated moments in the sagittal plane, i.e. flexion and extension. Studies found the relatively unexpected result that peak knee torque increased overly disproportionately compared to the carried load and ankle torque did the opposite (Han et al, 1992a; Quesada et al, 1996; Harman et al, 2000). No studies to the author's knowledge have investigated 3D joint kinetics with respect to load carriage, or assessed the effect of load carriage on joint powers.

2.6 Biomechanical Effect of Rifle Carriage

2.6.1 Introduction

So far the literature review has indicated that rifle carriage or restricted arm movements can have significant effects on parameters measured. This is specifically with respect to changes in stride parameters and sheer force at the shoulder. This section of the review will focus in detail on the effect of rifle carriage on biomechanical parameters. The effects of rifle carriage on either military, sporting or civilian populations have received very little attention in the published literature; this is in terms of both its biomechanical or physiological differences. It is also unclear to what effect carrying a rifle alters basal gait patterns, and if changes are observed to what extent do these put carriers at an increased risk of injury. Rifle carriage has two main effects, to add load to the anterior of the body and to restrict natural arm swing patterns.

2.6.2 Rifle Carriage Research

Rifle Carriage in the Military

While conducting this literature review no published work was found regarding the biomechanical or physiological effects of rifle carriage in a military context. More work is available regarding the effects of military load carriage on gait, which may or may not have been conducted while carrying a rifle. However, the specific effects that carrying a rifle may produce has been overlooked.

An area of obvious interest and importance to the military regarding rifle usage is the effect of numerous parameters on shooting performance. This has been covered in-depth with the effects of postural stability and experience (Era et al, 1996), rifle weight and handle length (Yaun and Lee, 1997), fighting systems (Tharion and Obusek, 1999) and load carriage (Knapik et al, 1997a) on rifle shooting performance being investigated.

Rifle Carriage in Sport

Biathlon ski racing involves both skiing and target rifle shooting. While skiing the athletes are required to carry a rifle of a minimum of 3.5 kg on the posterior of their trunk. The rifle is not carried in the arms for any prolonged period of time as the only time it is off the back is during target shooting when the athlete is stationary. The physiological effect of this rifle carriage on the trunk while skiing at increasing speeds has been investigated by Rundell and Szmedra (1998). Results showed an increase in metabolic cost with rifle carriage. An increased in heart rate, oxygen uptake, volume of air ventilated and blood lactate values were observed to increase in both males and females with rifle carriage during simulated skiing. As can be seen this study does not investigate rifle carriage in the arms, but is more akin to the studies looking at the physiological effect of load carriage. Studies has also concluded that improved rifle carriage economy on the trunk may be gained by: reducing the rifle mass; reduction in horizontal and vertical velocity and displacement during skiing; appropriate positioning of rifle such that load placement is close to the CoM of the body (Fredrick, 1987; Rundell and Szmedra, 1998).

2.6.3 The Effect of Rifle Carriage due to the Additional Load

As mentioned previously rifle carriage places load on the anterior of the body. Although this a relatively small load of 4.4 kg (the weight of the SA80 used by British troops) it does represent a shift forward in the body's CoM. As far as the majority of the literature is concerned load is carried on the back in a backpack or in the hands (either in front or by the side of the body). The biomechanical effects of load carriage have received considerable attention both within the industrial and military field; this has been covered in depth previously in this chapter (section 2.3).

2.6.4 The Effect of Rifle Carriage due to the Restricted Arm Swing

As well as shifting forward the CoM rifle carriage causes a restriction in natural arm swing patterns caused by the fixed arm position induced. Again during the current literature search no studies were found that specifically focused on the restriction of arm movements and their effects on kinetic parameters, let alone the effects of rifle carriage. Therefore much of this section will focus the function of the arms during walking, running or other activities and what affect natural arm swing has on basal gait patterns. A small number of studies have examined the effects of restricted arm movements on kinematic parameters of gait.

The Function of the Arms During Normal Walking

The normal human gait cycle involves the swinging of the upper arms in alternation, this movement is in phase with contralateral lower limbs (Webb et al, 1994; Wagenaar and van Emmerik, 2000). However, it has long been known that the arms do not simply act as 'pendulums' when walking but muscular activity drives them. At Columbia University, US in 1939 Herbert Elftman proposed a study to 'inquire whether the swinging of the arms in walking is merely that of pendulums reacting to the movements of their points of attachment or the movements are of muscular origin and play some part in the integrated activity of locomotion.' Results from his work suggested that the muscles of the arm actually exert considerable torque during locomotion. Also, that the swinging of the arms regulate the rotation of the body as a whole, especially about the vertical axis. During single support (only one foot in contact with the floor) the arms help bring the advancing foot into position for contact, and also modify the rotation of the trunk while both feet are in contact. Thus, the swinging of the arms serves to make a more gradual change to whole body rotations that occur during walking. (Elftman, 1939) concludes by stating 'the swinging of the arms is consequently not a purely incidental accompaniment of forward movement but is an integral part of the dynamics of progression.' This original work was later advanced and proven by Fernandez Ballesteros et al (1965) and Hogue (1969) who measured the EMG activity of the shoulder muscles. It was discovered that the main muscles used to drive the arm are the posterior deltoid, teres major and lattissimus dorsi.

The role of the arms as a stabilising and efficiency improving factor has not been as easy to determine, as the movement of the arms during gait are complex. However, relationships between upper and lower limb movement are synchronised to some degree. The shoulder and elbow exhibit maximum flexion (i.e. the arms are at opposite ends of their swing arc) during heel strike and maximum extension (arms almost vertical passing the trunk) during single support phase. These relationships also relate to the vertical height of the body's CoM with the maximum height occurring during single support and minimum at heel strike (Murray et al, 1967). Murray and colleagues also noted the stabilising effect of arm swing. They state that arm swing counterbalances excessive horizontal rotation of the trunk as the pelvis and thorax rotate simultaneously in the opposite directions. Also that the arms serve to modulate the vertical excursion of the body due to the upper limbs inverse relationship to its CoM (maximum arm swing occurs at minimum vertical height of CoM). These findings are also supported by Hinrichs and Cavanagh (1981).

Webb et al, (1994) proposed that the upper limbs display similar properties to pendulums, in that they will exhibit a natural pendular frequency which occurs at a certain stride frequency. This stride frequency was hypothesised to occur at the same time as arm swing changes from single to double swing per stride. During slow walking the arms will go through two full swings per stride, however at higher walking speeds this changes to the more typical one swing per stride. Results showed that participants avoided walking at a cadence exactly equal to their natural pendular frequency, and instead would walk just above or below this cadence. They suggested this was most likely so as to avoid walking in the transition zone between single and double swing as this may be uncomfortable and confusing (Webb et al, 1994). This transition only occurs at low stride frequencies (0.6 – 0.8 Hz) compared to normal walking (1.0 – 1.2 Hz).

The contribution of arm swing to momentum producing mechanisms has been called into question during walking (Murray et al, 1967) and running (Hinrichs, 1990). However, it is clear that for activities such as jumping (both in the vertical and horizontal plane) arms swing play an important role in improving performance (Feltner et al, 2004; Lees et al, 2004). The belief is that during walking the momentum produced by the forward swinging arm is negated by the opposite effect produced by the backward swinging arm, thus producing little or no increase in propulsive momentum. However, the muscles involved during flexion of the arm are usually larger muscle groups with the ability to produce greater torques than the muscles used during extension (e.g. the biceps and pectorals used during arm flexion verses the triceps and latissimus dorsi for extension). Therefore, even if the muscles involved in upper limb extension of one arm are activated or even experience a higher recruitment rate they may not be producing more torque than the flexors of the other arm. This needs further investigation to confirm that the arms only contribute to balance and a smoothing of the gait process.

Arm Function During Running and Other Sporting Activities

An extensive review of the function of the upper extremities during distance running has been completed by Richard Hinrichs published in the book 'Biomechanics of Distance Running' Edited by Peter Cavanagh (1990). The key and most relevant points will be highlighted here. Unlike when walking the arms actually increase the vertical oscillations of the body's CoM during running, rather than decreasing it. At a fast running speed the arms contributed to 7.1% of the total lift of the CoM. This is in contrast to walking as increased lift is beneficial as it aids the forward advancement of the body. Results also suggest that the arms do not contribute to the forward drive (or propulsion) of the body due to the relative forward momentum of one arm being cancelled out by relative backward momentum of the other arm. Again arm swing was shown to reduce the excursion of the body's CoM in the lateral (side to side) and anteroposterior (forward-backward) direction, when running on a treadmill. This may result in a decrease in energy cost and increase in stability. However, the single most important factor is the role that the arms play to balance the vertical angular momentum of the body. The arms generated alternate vertical momentums that tended to cancel out the opposite patterns in the legs. In short, if the upper body was not present the legs could not change direction when the body is airborne, and a recognisable swing phase would not be present (Hinrichs, 1990).

Research has been conducted looking at how arm swing can aid performance in the vertical jump. It is generally accepted that using the arms during a vertical jump increases overall jump height, but the mechanisms that contribute to this increase in performance are not fully understood. Lees et al (2004) suggest the arm swing enables the trunk to be inclined further forward at the beginning of the movement, thus enabling it to be extended earlier and faster. Also the build up of kinetic energy generated by swinging the arms is substantial. Although much of this energy is lost through the first 90% of the movement, during the last 10% an increase in vertical net force at the shoulder produces an upward force (or pull) on the trunk. Feltner et al (2004) suggest the increase in jump performance was due to a larger net impulse during the propulsive phase of the jump and an increase in maximum velocity of the CoM. The greater impulse observed was not as a result of increased vertical GRF being applied, but due to a longer duration of the propulsive phase.

Restricted Arm Swing and its Effects on Gait

As mentioned previously studies investigating the effect of restricted arm movements on gait patterns are very limited. Callaghan et al (1999) produced a study looking at the effect of walking speed and restricted arm movements on the biomechanics of the lower back. Restricted arm movements resulted in a decrease in axial twist and lateral bend at the lower back and also increased activation levels of 6 of the 7 EMG channels measured (external and internal oblique, latissimus dorsi, thoracic and lumbar erector spinae and multifidus all increased significantly but not the rectus abdominus). At first glance this seems to contradict earlier suggestions that natural arm swing counterbalances (or reduces) excessive horizontal rotation of the trunk. However, this rotation is mainly around the thoracic region and not at the lower back. Here the reduction in axial twist with restricted arm swing particularly at slower walking speeds produce a more static lumbar spine loading and motion patterns, which could be detrimental for certain injuries and tissues. Another benefit of arm swing during gait is the reduction of trunk muscular activation levels.

Eke-Okoro et al (1997) examined the alterations in gait from deliberate changes to arm swing patterns. The test conditions were: one arm restricted; both arms restricted; full excursion (exaggerated arm movements); pace walking (right arm forward with right foot etc); parallel swing (both arms move in same direction). Results showed that for each of the testing conditions maximum velocities decreased compared to their respective controls. In the conditions where one or both arms were restricted this decrease in velocity was caused by a decrease in participants stride length (constant stride frequency). The velocity change during the arm swing conditions (full excursion, pace walking and parallel swing) was attributed to a decrease in stride frequency (constant stride length). Restricted arm swing patterns lead to no changes in the stance time, however an increased stance time was observed with the exaggerated or abnormal arm swing conditions.

Harman et al (2001) produced a study that looked at the effect of different LCS on the biomechanics of load carriage. One of the packs used was a SPEAR LCS this was designed specifically for the Special Forces and although not a double-pack, per se, load is placed closer to the body's natural CoM. The other system was the MOLLE LCS which is standard issue to US ground troops. Of interest for this specific section of the review was the fact that the SPEAR system caused a restriction in rearward arm swing of 4 degrees. Harman and colleagues suggest that this restriction in arm swing resulted in the significant decrease in stride length between the LCS tested. This was independent to the decrease in stride length usually seen with an increase in carried load (Martin and Nelson, 1986). They suggest that the impediment of arm swing may reduce a soldier's ability to take longer strides when carrying lighter loads, but may not affect stride length when heavier loads are carried.

A case study looking at the effects of restricting arm swing during normal locomotion on one participant found that unilateral restraint of an arm during walking showed a significant decrease in horizontal displacement of the limbs (Marks, 1997). Along with greater inter-trial movement variability, a trend for greater thoracic rotation on the unrestrained side and altered angular velocity profiles for all upper and lower limb joints and the trunk. Concluding the study Marks (1997) states that restraining the non-dominant arm of a healthy individual disrupted their normal locomotor patterns suggesting less stable movement patterns.

Other Factors

Other factors relating to arm swing during walking have been noticed such as increase in upper limb RoM as cadence and walking speed increases (Murray et al, 1967; Shibukawa et al, 2001). This implies a greater walking speed elicits increased arm swing patterns. This may multiply the effects of restricted arm movement due to rifle carriage as military personnel will often be required to walk at a fast pace or even run over long distances.

The upper limbs are used as part of an important strategy to recover from a stumble where a full body response is initiated to help regain balance; bilateral shoulder abduction, internal rotation, elbow flexion and forearm pronation characterise the upper limbs response (Selby-Silverstein et al, 1997). Also when a fall occurs and results in impact to the pelvis, a complex series of upper limb movements allow the faller to impact the ground with the wrist at the same time as the pelvis, suggesting a sharing of contact energy between the two body parts (Hsiao and Robinovitch, 1998). It is clear that the arms play an important role in either recovering balance or breaking a fall. Rifle carriage reduces the ability of the carrier to initiate these protective measures. This coupled with the unpredictable terrain military personnel often traverse will increase the risk or severity of a potential fall. Rifle carriage may also reduce the carrier's ability to use support aids (including other people or objects) due to the fact that the hands are already occupied. This may reduce stability while walking and therefore increase the likelihood of a fall or impede recovery when a trip or fall is initiated. The comfort of carriers due to the forced postures as a result of supporting a rifle as well as the stress or strain placed on muscles of the trunk and upper limb has also received little or no attention.

2.6.5 Rifle Carriage in the Military

This section of the literature review is aimed at familiarising the reader with the rifle used by British troops and how this is carried by actual soldiers in the field. It is also worth highlighting the fact that a rifle is carried by military personnel at almost all times when on training or operations, either in the arms or supported by a sling.

The standard weapon as used by the British Army is the SA80 (A2) assault rifle. When military personnel are conducting exercises where an 'assumed threat' is present their weapon will on them at all times. This is further reinforced belief that the weapon is not fully under control unless there is a hand on it or indeed holding it. The method of rifle carriage used in this study would only normally be performed in a tactical situation where engagement with an enemy is likely, as the rifle is supported by both hands allowing it to be aimed and fired very rapidly. During normal marching, either with or without a load being carried, while on exercises or training the rifle would usually be carried with the aid of a sling. The sling is connected to the stock (front) and butt (rear) of the rifle and then passes over the left shoulder; the right hand is then placed on the pistol grip (handle) and controls the rifle. The sling enables the majority of the weight of the rifle to be supported at the shoulders, but still allowing the rifle to be brought to aim rapidly. Carrying the rifle in this manner allows the left arm to swing almost naturally (while evading the LCS and barrel of the rifle) and the right arm which is also controlling the rifle to swing across the body. The rifle can also be carried with the right hand on the pistol grip and left on the stock (still supported by the shoulder with the sling) and the entire ensemble moves forward and back in a restricted manor. The latter method of rifle carriage was adopted by the current study without the sling across the shoulders. The sling also allows the rifle to be drawn close to the body in front of the chest, thus both hands are free of the weapon enabling other tasks such as map reading or using binoculars to be conducted. The sling can be attached to the rifle in a way so as to act as straps allowing it to be carried on the back, this is particularly useful when skiing or while completing other tasks where both hands are needed for longer periods of time. This last method is unlikely to be used when any form of threat is present as it takes between 20 to 30 seconds to bring the weapon to aim from the back.

To conclude, the sling is used by the vast majority of military personnel when carrying the rifle, and is generally placed over the left shoulder and around the back finishing under the right arm and attaching to the butt of the rifle. It would be frowned upon and discouraged for the rifle not to be under control (at least one hand, the right, on the rifle) particularly amongst the infantry and other fighting units. However, during tactical situations or when engagement with an enemy is expected the rifle would be carried in both hands. This section was written from personal observations of military personnel during periods of rifle carriage, directly questioning military personnel who undertook experiments conducted by the author, and with personal communication with Major Iain Loynds of Dstl Fort Halstead.

2.6.6 Rifle Carriage Summary

No research investigating the effect of military rifle carriage is available either in terms of its physiological or biomechanical effects. Rifle carriage has two main effects, to add load to the anterior of the body and to restrict natural arm swing patterns. The arms do not act simply as pendulums but are driven by muscular activity. Natural arm swing counterbalances excessive horizontal rotation of the trunk and modulate vertical excursions of the body's CoM during walking. However, arm swing is not thought to contribute to the propulsion of the body. Restricted arm movements alter basal gait patterns by reducing preferred velocity and decreasing stride length. Natural arm swing aids balance by of stabilising the CoM in both the vertical and horizontal direction. This coupled with unpredictable terrain put rifle carriers at increased risk of falls, in addition rifle carriage itself reduces their ability to initiate protective measures.

2.7 Conclusions

The biomechanics of military load carriage has received a fair amount of attention in the literature, with some comprehensive studies and detailed discussions. However, through conducting this review certain gaps in the present knowledge exist. These include: What happens to GRF when heavy loads are carried, lack of clarity regarding the effect of altering load distribution on GRF parameters, absence of research investigating rifle carriage and 3D joint kinetics and kinematics.

Load carriage induces altered body kinematics, most commonly seen are increases in forward lean, knee flexion at heel strike and periods of double support as additional load is added. Vertical and anteroposterior GRF have been shown to increase proportionally to applied load, mediolateral parameters are inconsistent or ignored. However, the literature is inconclusive regarding whether or not protective mechanisms limit this increase at very heavy loads. It is generally recognised that distributing load more evenly around the trunk is both biomechanically and physiologically more favourable. Despite this specific changes to the kinetics of gait remain unclear. Joint kinetics (moments and powers) have all been shown to increase with load carriage in the sagittal plane. The research has highlighted that the knee undergoes a disproportionate increase in joint moments when load is added compared to other joints of the lower limb. Rifle carriage has two main effects, to add load to the front of the body and to restrict natural arm swing. It is unknown what effect that rifle carriage has on the biomechanics of gait. However, as military personnel will almost always carry a rifle when conducting periods of load carriage the potential effects need to be investigated.

Chapter Three – Experimental Equipment, Methodologies and Data Collection

3.1 Introduction

Chapters 4 to 7 of this thesis describe lab based studies investigating the effect of load carriage, load distribution and rifle carriage on gait. Throughout these chapters the same pieces of equipment and general methodologies were used. This chapter will describe in detail all of the equipment used to obtain these data and the justification for the methodology adopted. Equipment used ranged from a force plate, to motion capture system, to the backpacks actually used to carry the loads. Chapters 9 through 11 collect injury and discomfort data, methods used to collect this data will again be assessed for suitability.

3.2 Military Load Carriage Systems, Loads and Rifle

3.2.1 Military Load Carriage Systems

The military load carriage systems (LCS) used for this research were the Standard and AirMesh LCS. The standard LCS is called the '90 Pattern. This was developed following the Falklands War where the previous LCS the '58 Pattern was inadequate, as it became heavy, uncomfortable and shrank when wet. The '90 pattern was issued in 1988 and has been in use ever since under various guises. The second system is the AirMesh LCS; this principally is a double pack design with load distributed on the front and rear of the trunk. The AirMesh is a prototype LCS not in standard issue but has been trialled with the Special Forces. Another overhaul of the British LCS is currently being undertaken, as part of the Future Integrated Soldier Technology (or FIST) programme. The goal is to integrate a modular system of all equipment, weapons, sighting systems and radios that the individual soldier carries or uses, in order to increase his overall effectiveness on the battlefield. The equipment should be ready for issue in 2008/9 and issued to those who require it between 2015 and 2020.

Standard LCS

The standard LCS (figure 3.1) consists of a short back standard issue '90 Pattern Bergen (military term for a backpack) and PLCE (personal load carriage equipment) waist webbing. The webbing is supported by the shoulder with a yoke. Attached to the yoke is a waist belt, then up to 5 webbing pouches are fastened to the waist belt. Items which are carried in the webbing are things such as ammunition, first aid kits, food and water; in other words items needed to fight and survive if engaged in combat. Webbing will always be carried when on operations or patrols, and frequently during training procedures. Webbing can typically weigh up to 16 kg when loaded with necessary contents. The standard issue '90 Pattern Bergen comes in either short or long back and is again supported by straps and is worn over the top of the webbing. The backpack has an internal aluminium a-frame and is 120 litres in size. The backpack was designed so that the base of the Bergen sits on top of the webbing.

Figure 3.1: Standard LCS. Consists of PLCE waist webbing and '90 Pattern Bergen.

AirMesh LCS

The AirMesh Bergen was developed jointly by Loughborough University and the MoD, and formed a substantial part of previous research projects (Martin, 2001; Jones, 2005). The design features implemented in this Bergen were, plastic inserts in the shoulder and hip straps and the use of the AirMesh material. The AirMesh Bergen is worn with vest webbing; this was developed recently in order to be more suitable for use in military vehicles due to the exposed back. The main feature of the AirMesh

LCS of interest to the current thesis is that load is carried on both the anterior and posterior of the body, thus distributing the load more evenly around the trunk. Also important are: The functional hip belt that redistributes load from the shoulders to the hips; the plastic inserts in the shoulder and hip straps that reduce peak and mean pressure; and the improved thermoregulatory qualities provided by the AirMesh material used on the shoulder, back and hip body contact surfaces.

Figure 3.2: AirMesh LCS. Consists of PLCE vest webbing and AirMesh Bergen.

3.2.2 Loads

Loads Carried by Participants

The loads carried by the participants during all of the experimental work remained standard, with loads of 8, 16, 24, 32 and 40 kg carried. All loads were inclusive of webbing and/or Bergen. During the injury and discomfort research 24 kg was carried during the lab based studies and approximately 24 kg during the field trials. The field trials involved participants carrying LCS that they had packed themselves. The load of 24 kg was chosen as this was the load that military personnel would be required to be carried during the combat fitness test, this test formed the basis of the protocol in chapters 9 and 10.

During the biomechanical studies, loads were more easily controlled as the weights were pre-measured for the participants and the same LCS was carried by all participants. A minimum load of 8 kg was adopted as this closely represented the load that soldiers actually carry during combat. This is termed Assault Order and includes essential items that are needed when engaged in combat which includes ammunition, water bottle and field dressing. The second load was 16 kg, this closely resembled

Combat Order. Combat Order includes all the items carried above with the addition of 24 hour rations, waterproofs, spare clothing and bivi bag and other items. The next military loading order is Marching Order, this is represented by the 32 kg loading condition during the studies. Marching Order includes additional non essential items such as sleeping bag, shelter, additional food, clothes and water. Thirty-two kilos was the maximum load carried during the majority of the studies with the exception of the heavy load carriage study (chapter 4) where 40 kg was the maximum load. As stated in the methodology of chapter 4 (section 4.2.1) the additional 8 kg carried represents additional load that may need to be carried by members of the military on top of the Marching Order such as additional weapons, ammunition or equipment. Exact loads and carried items in the military loading orders cannot be disclosed for military clearance reasons, as this information is Restricted. The load of 24 kg used during the biomechanical studies was added as this was the load carried during the injury studies. The addition of load in 8 kg increments was adopted to assist with the statistical analysis and allow questions of proportionality to be addressed, even though this may not be identical to the load carried during the military loading orders.

Distribution of Load Within LCS

The load within the webbing or Bergen was distributed as closely as possible to how military personnel would pack their own kit. Regarding the waist webbing (figure 3.3) this equates to heavier left and right front pouches (1 and 5) as this is where the ammunition is carried. In the 16 kg webbing condition a relatively lighter rear pouch (3) in which water is carried. With respects to the vest webbing (figure 3.4) the heaviest pouches will be the front-bottom pouches (1 and 6), as again this is where the ammunition is placed. Table 3.1 shows the loads placed in the pouches of the two sets of webbing to make up the 8 and 16 kg. Load was added to the pouches by using pre-determined weighted steel rods and bagged sand. The steel rods were placed inside foam blocks inside the pouches, this insured the load was stable and remained evenly distributed. The sand was used when fractions of a kilo were needed or where rods did not fit easily into pouches (figure 3.5).

Figure 3.3: Top view of the waist webbing used and respective pouch numbers.

Figure 3.4: Anterior and posterior view of the vest webbing used and respective pouch numbers.

Table 3.1: Load placed in webbing pouch.

Webbing	Webbing Pouch (kg)					
	1	2	3	4	5	6
Waist 8 kg	1.0	1.0	1.3	1.0	1.0	-
Waist 16 kg	3.0	2.5	2.3	2.5	3.0	-
Vest 8 kg	1.5	0.5	1.0	1.0	0.5	2.0
Vest 16 kg	3.5	1.5	2.0	2.0	1.5	4.0

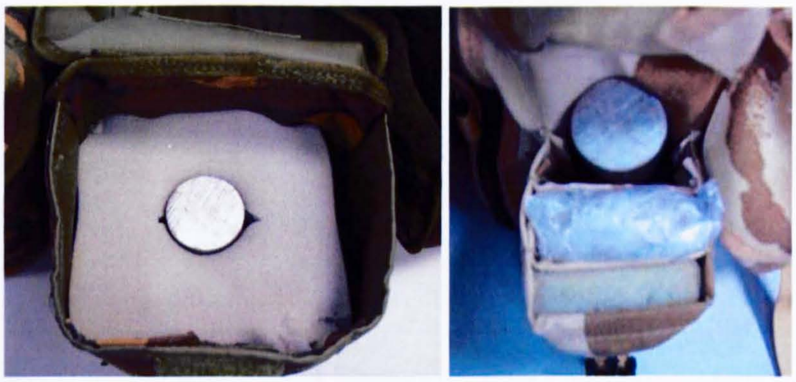


Figure 3.5: Steel rods and bagged sand distributed within the webbing pouches.

So far, only the loading of the webbing has been discussed, the load placed in the Bergens was added by using weight blocks. The weight blocks consisted of canvas bags with a steel plate at the bottom together with pieces of rectangular foam with circles cut out. These cut outs had steel rods placed inside them to make up the weights needed (figure 3.6). Again efforts were made to make this load distribution as realistic as possible. Another steel plate could be placed anywhere within the weight block with the steel rods sitting on this plate. This ensured that the load did not simply sit at the bottom of the pack, as efforts were made to locate the centre of mass of the weight block (and therefore Bergen) at around half way up the block. A proportion of the load (approximately 20%) was placed closer to the trunk. This again is a more realistic scenario as LCS are packed to keep the weight as close to the body as possible. Figure 3.6 shows the weight blocks that were used throughout the experimental testing. Shown are the steel rods placed in the foam, the central and larger hole is where the majority of the load was placed, the two smaller holes towards the rear are where a proportion of the load was placed closer to the trunk. These weight blocks were interchangeable between Bergens and 4 separate weight blocks were assembled to loads of 8, 16, 24 and 32 kg.

Figure 3.6: Weight block placed inside Bergens.

3.2.3 Replica Rifle

The rifle carried during the lab based studies was a replica SA80 (A2) assault rifle. The dimensions are equivalent to that of the actual rifle carried by British troops, although the weight of the replica is around half that of the actual rifle at 2.1 kg. The un-weighted replica rifle was carried during the heavy load carriage study (chapter 4). After this initial work the rifle was weighted so as to make it the same weight as the actual SA80 of 4.4 kg. Steel bars were taped bilaterally to the main body of the rifle and to the top of the stock of the rifle. The load distribution of the weighted rifle was closely matched to that of the actual rifle (figure 3.7). When assessing the effect of load carriage a rifle was always carried.

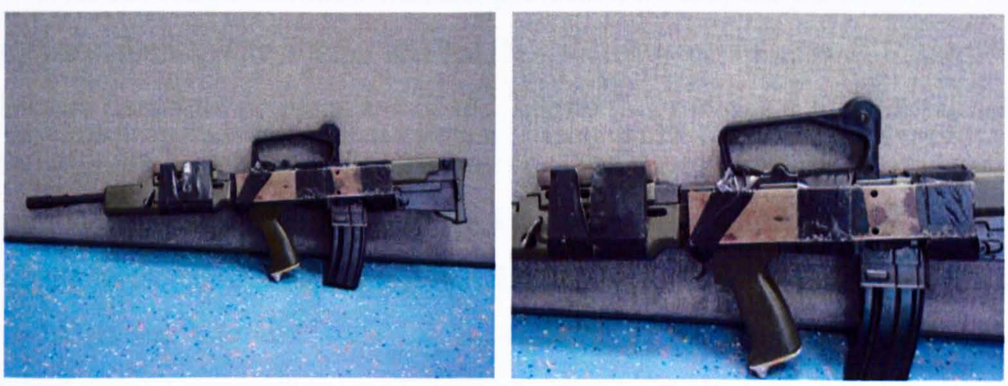


Figure 3.7: Weighted replica SA80 (A2) assault rifle

3.2.4 Boots and Socks

Keeping the footwear identical for all participants was an important aspect of the methodology as changing this would lead to alterations in gait patterns. Military boots have been designed for stability and durability, not necessarily flexibility and comfort. The standard issue leather boots used throughout the experimental studies have hardened rubber soles and lace up above the ankles. These features reduce injury to the sole of the foot and add stability to the ankle. These same characteristics reduce the attenuation of peak force during heel strike (Windle et al, 1999) and reduce the range of motion of the ankle joint (Harman et al, 2000), all aspects that are of interest to biomechanical studies. Participants had the choice to wear standard issue military woollen socks if desired (figure 3.8), however participants were allowed to wear their own socks if they wished.

Figure 3.8: Example of a pair of standard issue leather boots and woollen socks used throughout the experimental work.

With the longer duration walking protocols, as adopted for the injury studies, military participants were always utilised. Not all participants were full-time soldiers, but all were part-time or members of the Territorial Army (TA). These participants who had military experience all wore their own standard issue leather boots, not ones allocated to them by the Load Carriage Lab. With the biomechanical studies most participants were non-military personnel; for this reason boots were issued to them at the Load Carriage Lab and worn for the duration of the trial. As participants were only asked to walk about 8 m at a time it was not deemed as important that the boots worn were not their own or broken in by the participant. It was more important for the research that all wore the same footwear, and thus had the same cushioning and restricting properties. Approximately one quarter of participants who volunteered for the biomechanical studies had their own military leather boots, as they were members of the TA, officer training corps or members of the military from other countries who were studying at Loughborough University. These participants were allowed to wear their own standard issue boots if they wished, as boot properties would be identical to those issued from the Load Carriage Lab. Again woollen socks were available to all participants.

3.3 Participants, Recruitment and Ethics

All participants recruited for the experimental work volunteered to do so. A verbal and written explanation of the specific study was given, after which any questions could be raised. Health screen questionnaires were completed and finally signed informed consent was obtained. An example of the information sheet, health screen questionnaire and consent form can be seen in Appendix 3.1. Participants were informed that they had the right to withdraw from the trial without needing to give any reason or have their data removed at a later date. With the biomechanical studies part of the recruitment inclusion criteria were that all participants had to have previous experience carrying loads, but not necessarily in military LCS. Participants recruited ranged from experienced backpackers to members of the TA or Canadian military. However, the majority were students or staff from Loughborough University who had carried backpacks before. All participants who took part in the injury and discomfort studies (chapters 9 to 11) where either full- or part-time members of the military. Participants for the questionnaire section of chapter 9, and the joint and bone discomfort study (chapter 10) were all, with the exception of one participant, members of the East Midlands Officer Training Corps (OTC). Members of the OTC study for their degrees at universities in the Midlands, after this they enter the armed forces as officers. OTC members conduct military activities between once and four times a month and attend a summer camp once a year for a period of two weeks. Although they are not full-time soldiers they regularly undertake military activities and exercises and will eventually be full-time soldiers. Participants who took part in the interview section of chapter 9 were full-time soldiers from the 1st Regiment Black Watch. Due to the military commitment of the UK in the Middle East during periods of testing for this research, the soldiers on base were of relatively young age with little operational experience. Finally, participants who completed the load carriage injury questionnaire in chapter 11 were students and staff from Welbeck College, Leicestershire. Welbeck is a residential defence 6th form college which aims to provide students with a rounded education designed to meet the needs of a modern and technical Armed Services. Students who completed the questionnaire were in the upper 6th (or year 13) and aged between 17 and 18. Staff that completed the questionnaire were those who had military experience, not necessarily just academic teachers.

Ethical clearance was granted by the Loughborough University Ethical Advisory Committee for all experimental work undertaken. The generic load carriage protocol (G03/P18) formed the base of all ethical submissions and was sufficient to cover the majority of the experimental work conducted. However, further ethical clearance was required for the heavy load carriage study (chapter 4), as the percentage of load carried was above the 40% of bodyweight provided by the generic protocol. Ethical clearance was granted for loads of up to 40 kg to be carried over relatively short periods of time (R04/P57). Prolonged periods of load carriage of up to 2 hours as experienced by participants in the chapter 9 study was granted ethical clearance (R03/P98). The distribution of questionnaires to students under the age of 18 also required separate ethical clearance. A proposal was made and accepted under the condition that it was made explicitly clear that completed questionnaires would be returned to the investigators directly, and would not be seen by college staff (R05/P122). In addition to Loughborough University, permission was obtained from Black Watch and OTC commanding officers and the Principal of Welbeck College as appropriate.

3.4 Gait Analysis Equipment

3.4.1 Coda Motion Analysis System

The final biomechanical study (Chapter 7) was a 3D bilateral gait analysis of load carriage. To achieve the aims of the study, both the force plate (described in section 3.4.3) and two Coda motion analysis systems (described below) were used in conjunction to collect lower limb kinetic, kinematic and spatiotemporal data. The previous biomechanical studies (Chapter 4 – 6) were only concerned with collecting kinetic data, for this the Coda Mpx30 and Kistler force plate were used in conjunction (again see section 3.4.3).

The Coda motion analysis system is a general purpose 3D motion tracking system. Each Coda scanning unit contains three pre-aligned solid-state cameras which track the position of a number of active markers (in the form of infra-red Led's) in real time (figure 3.9). The angular resolution of each camera is about 0.002 degrees; this results in a lateral position resolution of about 0.05 mm in the horizontal (x) and vertical (z) axis at 3 m distance from the camera and a distance resolution (y axis) of around 0.3 mm. The CodaMotion software provides the user interface to the Coda hardware for real-time data display and data acquisition. The software was designed for general purpose motion analysis, but has special functions for clinical gait analysis. The software allows the user to define joint angles from the relative position of any markers and, combined with kinetic data, can calculate joint powers and moments. As well as this marker velocities and accelerations, and distances between markers are calculated automatically and available for plotting. The software also allows an animated stick figure of the gait cycle to be viewed and graphs of the selected data (either joint angles, marker positions etc) to be viewed in real-time. This is very beneficial in determining if good data from a trial has been collected. The acquired data is principally stored in a binary format unique to CodaMotion (.mdf file). Data may however be converted into a text format suitable for exporting into spreadsheets or word processing documents.

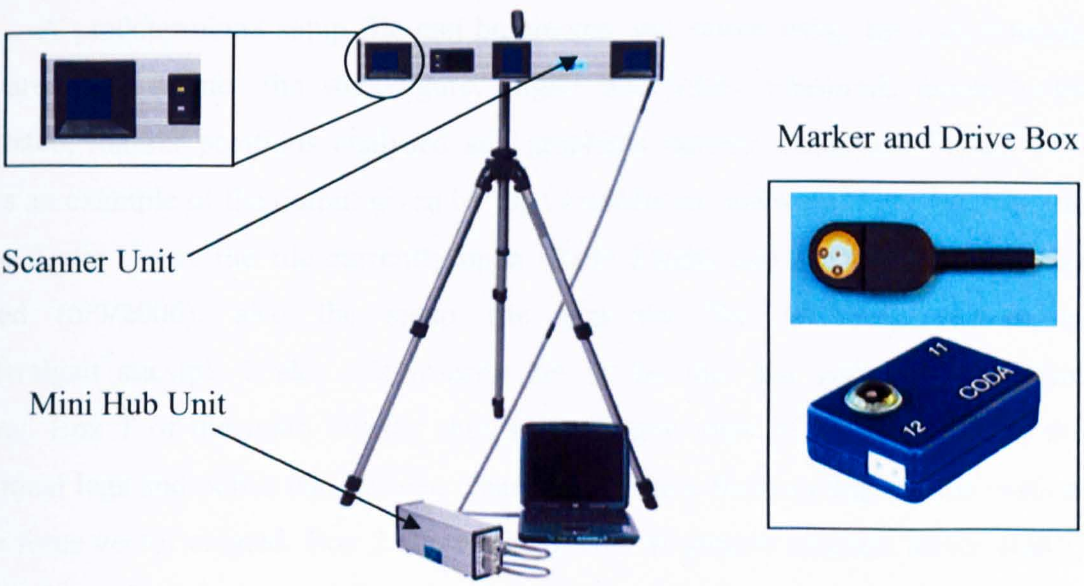


Figure 3.9: Coda Cx1 Motion Analysis System and active markers.

Two versions of the Coda Motion Analysis system are now available and used during the experimental work for this thesis, the Mpx30 and Cx1. The Mpx30 was the original system designed by Charnwood Dynamics and is larger and heavier than the newer Cx1. The other major difference is the PC connectivity; the Mpx30 needs an industrial PC with ISA slots on board while the Cx1 can be connected via serial ports more commonly found on desktop PCs and laptops. The user interface, namely the CodaMotion software, is generally the same for both systems. Figure 3.9 shows the Cx1 system. As mentioned previously both systems use active markers, or infra red Led's, to track the position of body segments. Other systems may use passive markers that reflect certain wavelengths of light and are detected by the cameras. The main disadvantage with these systems over the active marker systems is the fact that the cameras detecting the markers and the related software do not know where a specific marker has been placed. This has to be defined after the data has been collected and hence the data cannot be displayed in real time. When using the Coda system, small infrared Led markers are placed on the participant to be analysed. These are powered by small marker drive boxes containing rechargeable batteries which are also placed on the subject (figure 3.9). Circuitry in the drive boxes activates up to 56 markers in a rapid time multiplexed sequence. This provides each marker with its intrinsic identity, so the Coda hardware and software always know which marker is which, even when they are positioned close to each other. There is never any possibility of confused or fragmented trajectories.

A predetermined setup file can be created and stored using the CodaMotion software. This defines the stick-figure, angles and joints measured, forces to be calculated, marker positions analysed and graphical outputs displayed. Figure 3.10 shows an example of the output given by the CodaMotion software. The very top line of the figure shows the file currently open (Rifle 2.mdf) and the date this file was created (6/3/2006), also the setup file that the file is being viewed in (bilateralgait_stu.stp). Under this information is the tool bar and then the main display. Box 1 of the main display shows an oblique view of the stick-figure, the individual legs and pelvis can be seen clearly, the purple line running almost vertical is the force vector created. Box 2 shows the 3 axes of ground reaction forces (GRF) for the foot which is in contact with the force plate (right foot). Box 3 shows the moments and powers experienced by the joints of the right leg. Box 4 is a frontal stick-figure view. Finally, box 5 shows the joint angles of the lower limb.

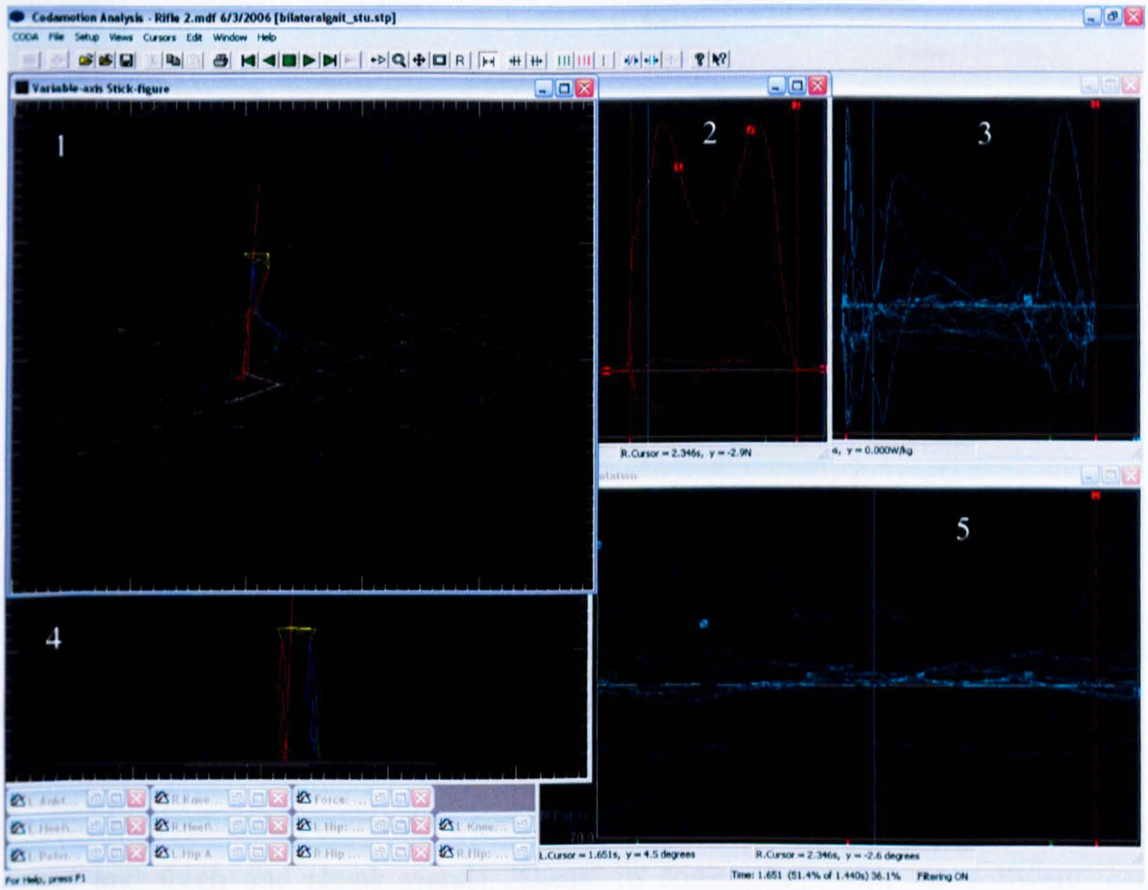


Figure 3.10: Example output from the CodaMotion Software.

3.4.2 Coda Gait Analysis Package

The Coda motion analysis system can also be used with a 3D segmental gait analysis package. A special marker set, when used in conjunction with the CodaMotion software, has the ability to calculate the internal joint centres and 3D internal rotations for the hip, knee and ankle joints. In addition the 3D orientation of the pelvis and foot are also calculated. If force plate data are acquired then the GRF data during stance and 3D moments of the hip, knee and ankle can be calculated using inverse dynamics modelling of each leg segment. Total power dissipated in each joint is also calculated. Further information is required to calculate the internal joint centres and for the inverse dynamics calculations. This includes information such as participant age, height and weight, in addition to joint and pelvis dimensions. The joint widths and pelvis width and depth were measured before the markers are attached to the body and inputted manually into the patient data file. The hip joint centres are estimated by using a standard linear regression model closely based on the pelvis model described by Bell et al (1989) as taken from the Coda Cx1 user manual.

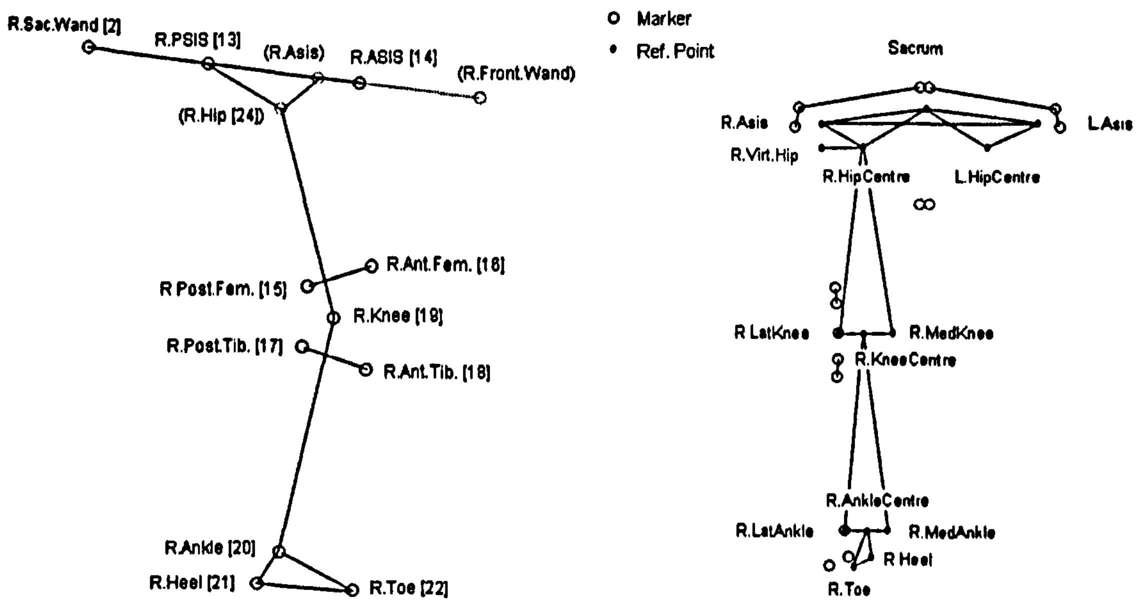


Figure 3.11: Right leg marker positions and joints and segment derived from these markers, taken from CodaMotion V6.64 user guide.

As mentioned previously a special marker set was used, consisting of a pelvic frame and thigh and shank wands. These, in conjunction with the software, can measure the 3D movements of the joints. Twenty-two markers are used to define the lower limbs and hips, some markers are placed directly on the skin others onto the frame and wands. Figure 3.11 shows the marker setup required (right leg only) for gait analysis and the reference points and joints derived from these markers. The data acquired are then displayed in real time in Coda Motion software in an output similar to figure 3.10. Again from here data can be exported into a spreadsheet for further analysis.

3.4.3 Force Plate

The force plate used during the biomechanical studies was a Kistler Portable Multicomponent Force Plate for Biomechanics with built in amplifier, Type 9286AA, dimensions 60 x 40 x 3.5 cm (figure 3.12). The force plate provides dynamic and quasi-static measurement of the 3 orthogonal components of force (F_x, F_y, and F_z) acting from any direction on the top plate. With the addition of optional software, moments, centre of pressure, torque and centre of mass displacement and acceleration can also be measured. Force which is applied to the top of the force plate is distributed between four 3-component force sensors arranged between the mounting base and top plate (figure 3.12). Each of the sensors has three pairs of quartz plates, one is sensitive to pressure in the vertical direction and the other two in the anteroposterior and mediolateral direction. The electrical charges yielded by the force plate are strictly proportional to the measured quantities, they are then converted by charge amplifiers into analogue voltages.

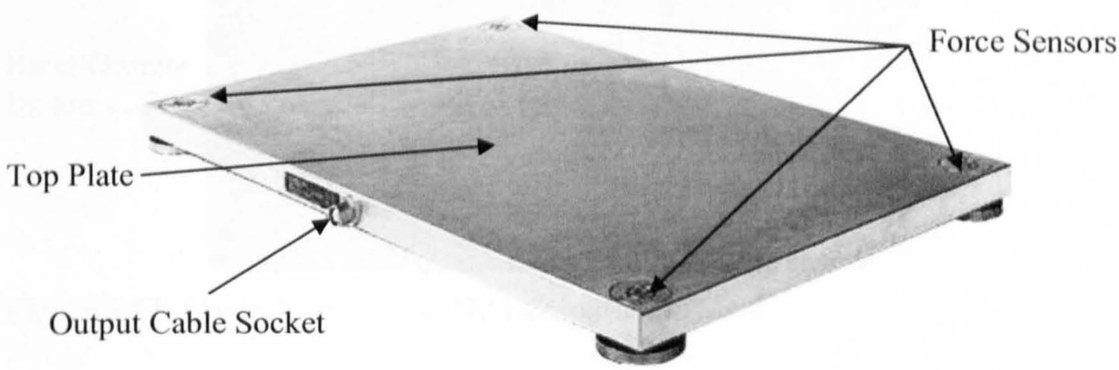


Figure 3.12: Force Plate, Type 9286AA, with important features identified. Picture taken from Kistler instruction manual.

A Control Unit, Type 5233A2 (figure 3.13), was used to supply power to the force plate as well as acting as a remote control to set the measuring range and reset and/or operate the system. The analogue signals created in the 4 force sensors are converted to digital information which can be read by PC software via an analogue to digital converter (A/D converter). The A/D converter was situated on board of one of the Coda Mpx30 ISA cards, this has the ability to covert 8 channels of analogue data received from the force plate to digital data that can be read by the CodaMotion software. The force plate is connected to the control unit via a connecting cable, Type 1760A10. The control unit then relays the 8 channel kinetic data to the A/D converter in the ISA card of the Mpx30 via another connecting cable, Type 1500B5 (figure 3.13).

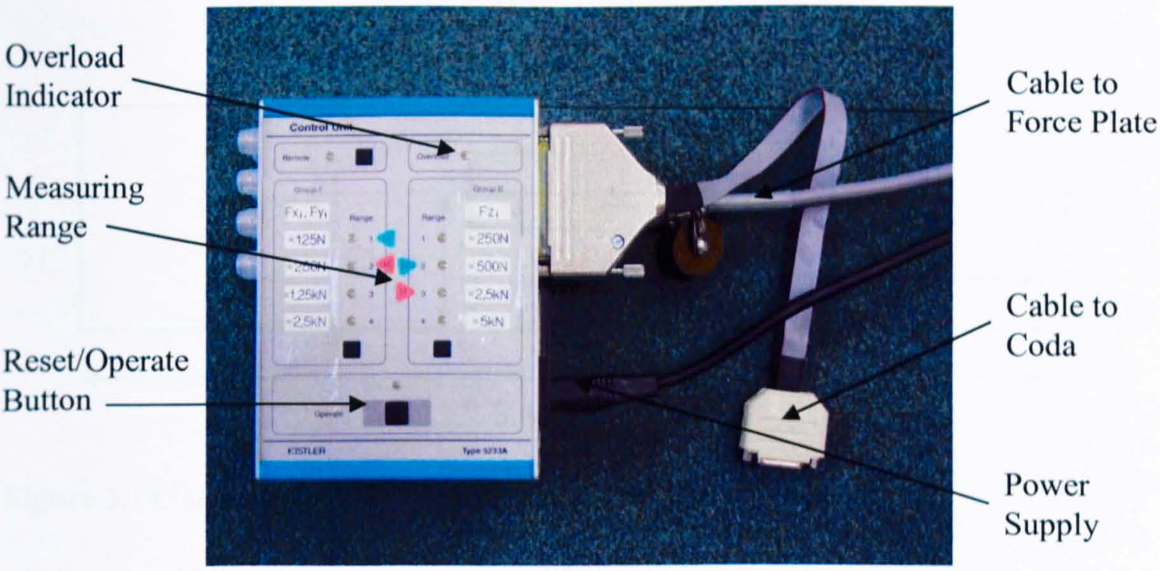


Figure 3.13: Control Unit, Type 5233A2, with important features identified.

The use of the Coda Mpx30 and CodaMotion software to collect force data, and not another form of A/D converter, is a very reliable method which has been rigorously tested by Charnwood Dynamics. The Coda software used for this thesis was designed specifically for Kistler force plates and this specific control unit. The main disadvantage of this method of force data collection is the restricted sampling frequencies, as only up to 800 Hz can be sampled instead of the 1000 Hz the Kistler force plate is capable of. The other disadvantage of this method is that the force data has to be captured with the CodaMotion software which offers limited ground reaction force (GRF) analysis. Therefore the data were exported from CodaMotion into Microsoft Excel where the calculation of maximums, minimums, times, rates and impulses were conducted.

3.4.4 Walkway

The walkway during the biomechanical studies housed the force plate. The force plate was embedded flush into the walkway, it was however not placed in the centre of the walkway but slightly off centre both horizontally and vertically (figure 3.14). This gave a slightly longer approach to the force plate which aided in achieving a natural gait pattern. Also, the placement of the walkway slightly off centre ensured the participants, who were predominately right footed, walked down the centre of the walkway.

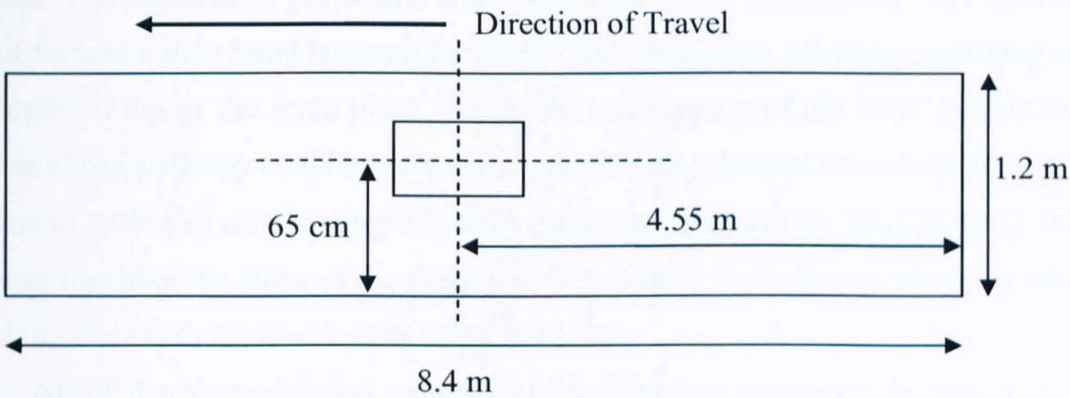


Figure 3.14: Dimensions of walkway and placement of force plate.

The walkway was built in house to and was constructed of two pieces of 18 mm MDF screwed and glued together. The two pieces of MDF overlapped by 10 cm, this allowed the pieces to be slotted together almost like a jigsaw and gave added stability to the completed structure (figure 3.15). The walkway generally consisted of two piece sizes, one 70 x 70 cm and the other 50 x 70 cm, from which the 8.4 x 1.2 m walkway can be constructed.

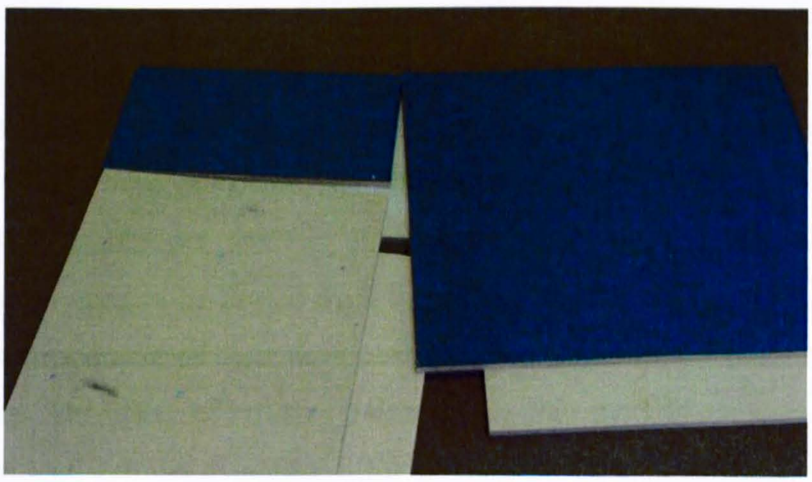


Figure 3.15: Sections of the walkway.

Placed on top of the wooden surface was carpet (figure 3.15). This was chosen because of its non-reflective surface, as shiny surfaces will interfere with Coda causing marker drop out at the foot and reflections that may be interpreted by Coda as other markers. Carpet is also a rugged non-slip surface that will not be a hazard when walking on. The carpet was fixed to the top of the force plate using silicon sealant. The carpet is relatively firm and did not compress when walked on, this in turn will not alter the cushioning properties and change the GRF parameters. The silicon sealant formed a tight bond between the carpet and force plate, allowing no sliding of the carpet on top of the force plate. Due to the overlapping of the MDF boards the sections of the walkway could be screwed together. This principal was adopted for the sections of walkway surrounding the force plate, and negated the possibility of the walkway touching the sides of the force plate or causing unnecessary vibrations that would interfere with the kinetic data being collected.

All of the biomechanical experimental testing was conducted in one of two places, either the Load Carriage Lab in the John Clements building or the Ergonomics Lab in the Wavy Top building, both on campus at Loughborough University. Important considerations for both the walkway and force plate are the surface that they are placed upon. The floor needs to be very firm and flat, this avoids rocking of the force plate and ensures both the force pate and walkway are placed on stable foundations. In both laboratories the force plate and walkway were placed on a solid, non-slip, concrete foundation floor.

3.5 Obtaining a Representative Gait Cycle

Ensuring the data collected are representative of typical gait is always a challenge, particularly when testing in the artificial lab setting. These studies can only take a 'snap-shot' of the gait cycle; the effect of prolonged marching on gait was not an aim of this thesis. As well as ensuring the gait cycle is representative the participants used need to be drawn from the same sub-population. Military personnel spend a large proportion of their time carrying loads especially during basic training and operations. The effect of military training may alter the gait cycle and completely inexperienced load carriers may also differ to experienced load carriers.

3.5.1 Number of Repeat Trials

The number of repeat trials needed in order to generate a stable mean with GRF data has been examined in the literature. In 1983 Bates et al assessed the within-subject variability for running gait GRF parameters; they concluded that a minimum of 8 trials were necessary to obtain stable data. Hamill and McNiven (1990) investigated the same issue but during walking, they suggest that if comparisons between conditions on a single day were necessary, then each condition should include 10 trials. Both of these studies estimated that stability occurred when all successive mean deviations fell within one-quarter standard deviation of the 10 or 20 trial mean for that variable (Bates et al, 1983; Hamill and McNiven, 1990, respectively). These studies suggest that 10 repeat trials should be conducted enabling the data to be 'Compared with the knowledge that the measures were reliable.' In addition to this Ferber et al (2002) suggest that GRF data were more reliable between testing sessions (two sessions on either the same or different days) as compared to kinetics and kinematics. Kadaba et al (1989) suggest that vertical and anteroposterior GRF parameters are more repeatable than mediolateral forces between testing sessions. They conclude with the statement 'It may be reasonable to base significant clinical decisions on the results of a single gait evaluation.' Implying that multiple assessments are not needed to establish the gait characteristics of an individual. This does not however refer to only one repeat trial being conducted.

Even though the studies mentioned above have stated that 10 trials are needed to obtain a stable mean the vast majority of load carriage studies have not used these number of repeat trials, but used between 3 (Lloyd and Cooke, 2000; Harman et al, 2000) and 5 trials (Tilbury-Davis and Hooper, 1999; Hsiang and Chang, 2002; Buntemgchit, 1989; Crosbie et al, 1994). However, certain studies have used 10 repeat trials (Kinoshita and Bates, 1983; Kinoshita 1985; Wiese-Bjornstal and Dufek, 1991, Jones et al, 2001).

As well as reviewing the literature to determine the number of repeat trials necessary to obtain a stable mean, a preliminary investigation was conducted for this thesis. Using the method adopted by Bates et al (1983) and Hamill and McNiven (1990), the effect of 50 repeat trials were analysed. They suggest that a stable mean is assumed when the mean values are consistently within 0.25 of the final standard deviation. Fifty walks were completed by a single participant along the walkway striking the force plate with their right foot, at a walking speed of 1.5 $m.s^{-1}$ (± 5%). Following this the major GRF parameters were analysed and means and standard deviations for 1, 2, 3, 5, 7, 10, 12, 15, 20, 25, 30, 35, 40, 45 and 50 trials were calculated. Figure 3.16 shows the cumulative mean for the specific number of trials for each of the GRF parameters analysed. The bold dashed lines indicated the range of ± 0.25 of a standard deviation from the 50 trial mean. The parameter has been deemed to reach a stable mean when the line is consistently within these two dashed lines, this is highlighted on the graphs.

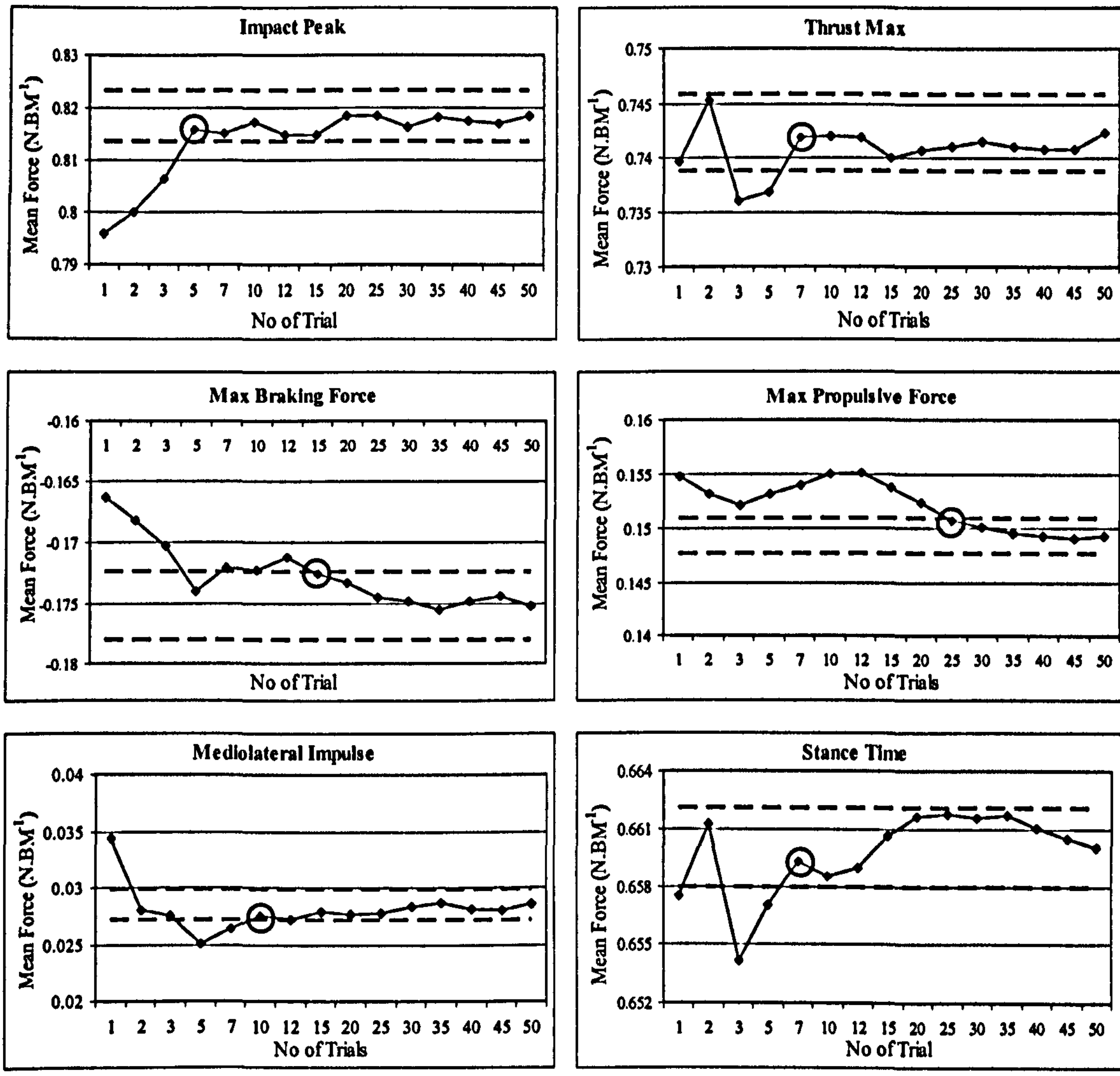


Figure 3.16: Analysis to determine the number of trials needed for a stable mean to be reached for selected GRF parameters.

Figure 3.16 shows the cumulative means for selected GRF parameters and highlights when they have become stable, according to the criteria adopted. It is worth noting again that this analysis was only conducted with one participant, and it was carried out in trainers with no rifle or load carried, it was never intended to be an in-depth trial analysis. Results do however suggest that the vertical GRF selected, the impact peak and thrust maximum, reached a stable mean after 5 and 7 trials respectively. Also, the mediolateral impulse reached a stable mean after 10 trials, which is beneficial to know as this thesis, unlike many other biomechanical load carriage studies, is interested in the force produced in the mediolateral axis. Stance time was seen to stabilise after 7 trials. Finally to the anteroposterior forces, the maximum braking and propulsive forces, figure 3.16 shows that these forces did not stabilise until 15 and 25 trials respectively. Although these numbers are obviously high and above the 10 trials used during the thesis, this may just be due to particularly high variability within this participant or during that specific testing session. In general this analysis is in agreement with previous studies (Bates et al, 1983; Hamill; McNiven, 1990) that 10 trials are sufficient for a stable mean to be achieved when collecting GRF data.

3.5.2 Kinetic and Kinematic Sampling Frequencies

It is suggested that during normal human gait the kinematic activities that are observed have frequencies ranging between 10 and 30 Hz (Craik, 1995). Winter et al (1974) concluded that for the knee 99.7% of signal power existed below 6 Hz. It is well established that preferred sampling frequencies should be twice that of its fastest component. Kinematic data collection studies within the load carriage literature have used a wide range of sampling frequencies from 50 Hz (Martin and Nelson, 1986; Quesada et al, 2000; Fiolkowski et al, 2006), 60 Hz (Harman et al, 2000; Polcyn et al, 2002), 100 Hz (Kinoshita, 1985, LaFiandra et al, 2002; Holt et al, 2003; LaFiandra et al, 2003; Fowler et al, 2006), 120 Hz (Ren et al, 2005) to 200 Hz (Attwells et al, 2006). As highlighted here the most regularly used sampling frequency is 100 Hz. The disadvantage with sampling at too higher frequency is the amount of data that needs processing. This is a particular issue when digitising images from video as it may double the number of frames of footage that need to be processed and makes for a laborious process. For this reason kinematic data collected by video will usually sample at the lower frequencies of 50 and 60 Hz. When motion capture is used the issue of capturing too much data is not as prominent, particularly when active markers are used as with Coda. In this case higher sampling frequencies (100 and 200 Hz) will just lead to larger file sizes and increased need for computer storage.

Kinetic and in particular GRF data needs to be sampled at a higher frequency compared to kinematic data; principally this is as a result of the heel strike transient. The heel strike transient is a high frequency impulse load that occurs just after heel strike. The phenomenon occurs during almost 90% of walking trials and may be caused by the variation in muscular activation timings of the lower limb (Verdini et al, 2000). The frequency that the heel strike transient occurs has been shown to be from between 10 and 75 Hz, and its magnitude can be up to 1.25 time bodyweight (Simon et al, 1981). Research by Lafortune et al (1995) showed that 98% of GRF data was present below 100 Hz and therefore they used 100 Hz as their cut off frequency. The sampling frequency for kinetic data is generally not regarded as an issue as force plates commonly utilise frequencies of 1000 Hz. During walking a sampling frequency of 200 Hz will be sufficient to capture all GRF events; however, during running or more dynamic activities this may need to be increased. Force plate frequencies used to measure GRF data again vary within the load carriage literature from 400 Hz (Kinoshita, 1985), 500 Hz (Wiese-Bjornstal and Dufek, 1991; Quesada et al, 2000; Hsiang and Chang, 2002) 1000 Hz (Harman et al, 2000; Polcyn et al, 2002; Schiffman et al, 2006). Hamill and McNiven used a force plate sampling frequency of 400 Hz when assessing the reliability of GRF parameters in 1990. In conclusion, sampling frequencies for the biomechanical studies conducted for this thesis will be 400 Hz for kinetic data and 200 Hz for kinematic data.

3.5.3 Participant and Training Effects

Military personnel undergo a substantial period of basic training, usually around 6 weeks, before they are accepted into the armed forces. After this basic training soldiers will undertake regular military training, exercise and patrols during their time in service. Much of this will involve load carriage. To the author's knowledge no study has investigated the effects of military or load carriage training or experience on gait. The majority of 'task experience' research is focused on the interrelationships between individual and group experience on decision making, leadership, teamwork and task progression and outcome. It may however be fair to conclude that significant load carriage experience may lead to minimised biomechanical or physiological cost of gait. Regular load carriage has been shown to increase the aerobic capacity (or VO_{2max}) of low fitness level civilians (Shoenfield et al, 1980) and Australian military recruits with a high level of initial fitness (Rudzki, 1989). Again no study has investigated the biomechanical effect of load carriage training on gait. A review of the literature by Haisman (1988) suggests that an individual's physical capacity will influence their ability to perform load carriage. The main determinants of load carriage ability were age, anthropometry, aerobic and anaerobic power, muscle strength, body composition and gender.

With no known training effect present on the biomechanics of gait, and the difficultly of obtaining full-time military personnel to conduct the experiments, it was deemed acceptable to use civilian participants for the studies. However, efforts were made during recruitment to ensure the participants who volunteered led active lifestyles, were of moderate fitness levels and had previous experience of load carriage. This minimised the training effect, and in conjunction with the short periods of load carriage adopted for these studies, made for what the author believes to be comparable research conclusions.

3.5.4 What Walking Speed to Adopt?

A walking speed of 1.5 $m.s^{-1}$ (5.4 $km.h^{-1}$ or 3.4 mph) was selected as the target speed for all the biomechanical experimental work. This represents a brisk walking pace as would be used by members of the military when marching. The walking speed adopted is slightly lower but equivalent to speeds marched during a Basic Combat Fitness Test which is used to assess combat readiness of British Troops. During this test soldiers have to cover 12.8 km in 2 hours whilst carrying 24 kg, this is equivalent to 1.78 $m.s^{-1}$. The walking speed was reduced from 1.78 to 1.5 $m.s^{-1}$ as pilot studies highlighted numerous issues with the higher walking speed. Less tall participants found the speed too quick to attain comfortably, due to their shorter stride length and therefore increased stride frequency. When walking towards the top of a participants speed range the stride parameters and actual walking speed were more variable and a constant walking speed was difficult to maintain. Nilsson and Thorstensson (1989) suggest that the transition from walking to running usually occurs at around 2.0 $m.s^{-1}$. This speed may be lower for certain participants and result in significant changes to the gait pattern. A walking speed of 1.5 $m.s^{-1}$ was also adopted by Harman et al (2000) and Martin and Marsh (1992) who state that 'This speed is within the range of preferred walking speeds of healthy young adults typically reported in the literature.'

To measure the walking speed of the participants three pairs of infra-red photoelectric cells or light gates (Brower™ SpeedTrap II, figure 3.17) were used. Each pair consisted of an infra-red emitter and receiver (IRE and IRD-T175, respectively). When the beam was broken between the emitter and receiver a radio signal is transmitted to the Coaches Monitor (CML5MEM) which starts the timer. The specific set up for this thesis placed 3 pairs of light gates 1.5 m apart from each other. The first pair activated the timer, the second recorded a split time for the approach to the force plate and the final pair the time to complete the 1.5 m section after the force plate (figure 3.18). As the light gates were placed a known distance apart the speed could be calculated. For this research both speeds had to be within the desired range thus limiting the potential for acceleration or deceleration that would affect the GRFs produced. An acceptable range of ± 5% from the target walking speed was selected in line with other research (Kinoshita, 1985; Wiese-Bjornstal and Dufek, 1991; Lloyd and Cooke, 2000; Polcyn et al, 2002). Hamill and McNiven (1990) also used a range of 5% for their research assessing the reliability of GRF parameters during walking.

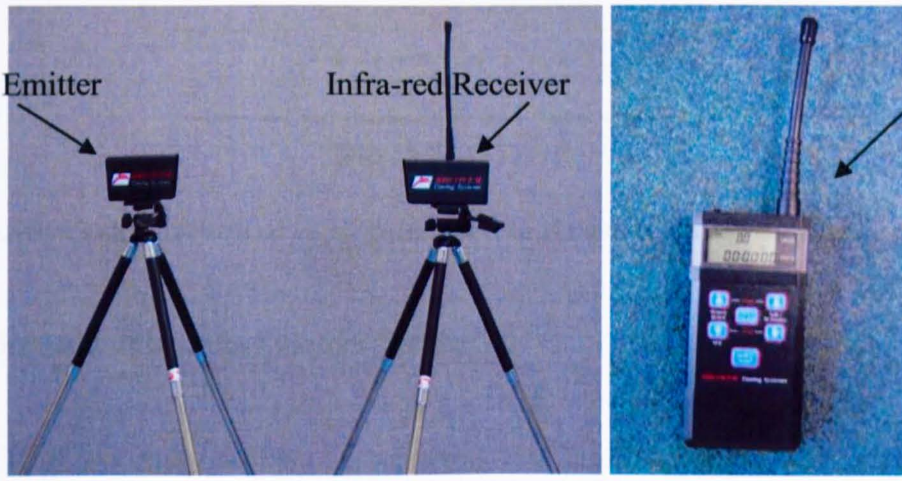


Figure 3.17: Brower SpeedTrap II timing system.

It was deemed important that three sets of light gates were used to ensure a constant walking speed was maintained throughout the target areas. It is well established that an increase in walking or running speed increases the GRF produced (Cavanagh and Lafortune, 1980; Hamill et al, 1983). Pilot studies conducted for this thesis showed that despite a mean speed of 1.5 m.s^{-1} being maintained throughout the 3 m target area walking speeds could differ by as much as 25% between the approach and depart zone of the walkway (1.3 – 1.7 m.s^{-1}). The speed variations observed during the pilot study may have been due to the increased difficulty to regulate walking speed while carrying heavy loads compared to unencumbered walking.

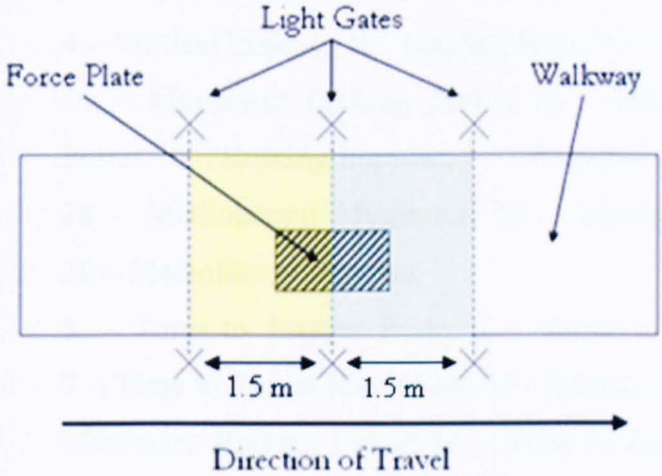


Figure 3.18: Configuration of light gates used to measure walking speed.

3.6 Biomechanical Parameters Measured

There are many different parameters that could be measured and calculated with gait analysis, approximately 100 different parameters all giving information about a participant's gait cycle. It is unnecessary to analyse and report all of these so the most important parameters need to be determined. Another factor for not assessing too many variables is a statistical one. If 100 parameters were tested then the probability that we will generate a Type I statistical error is high. The following section will outline the parameters which have been selected for analysis throughout this thesis. They will be grouped into ground reaction force, kinetic, kinematic and spatiotemporal parameters.

3.6.1 Ground Reaction Force Parameters

Bates et al (1983) identified 42 GRF variables in all 3 axes during running, from these they highlighted 19 as important enough to retain for their model. Kinoshita in his 1985 load carriage study identified 16 parameters. Hamill and McNiven (1990) also identified 16 parameters. None of these studies highlighted loading or push-off rate as parameters, unlike Hsiang and Chang (2002). The GRF parameters chosen (figure 3.19) for analysis for research conducted through this thesis were:

Vertical	1 – Impact Peak; 2 – Force Minimum; 3 – Thrust Maximum; 4 – Vertical Impulse, 8 – Loading Rate; 9 – Push-Off Rate.
Anteroposterior	11 – Maximum Braking Force; 12 – Maximum Propulsive Force; 16 – Braking Impulse; 17 – Propulsive Impulse.
Mediolateral	18 – Mediolateral Minimum; 19 – Mediolateral Maximum; 20 – Mediolateral Impulse.
Time	5 – Time to Impact Peak; 6 – Time to Force Minimum; 7 – Time to Thrust Maximum; 10 – Stance Time; 13 – Time to Maximum Braking Force; 14 – Time to Zero Newton's; 15 – Time to Maximum Propulsive Force.

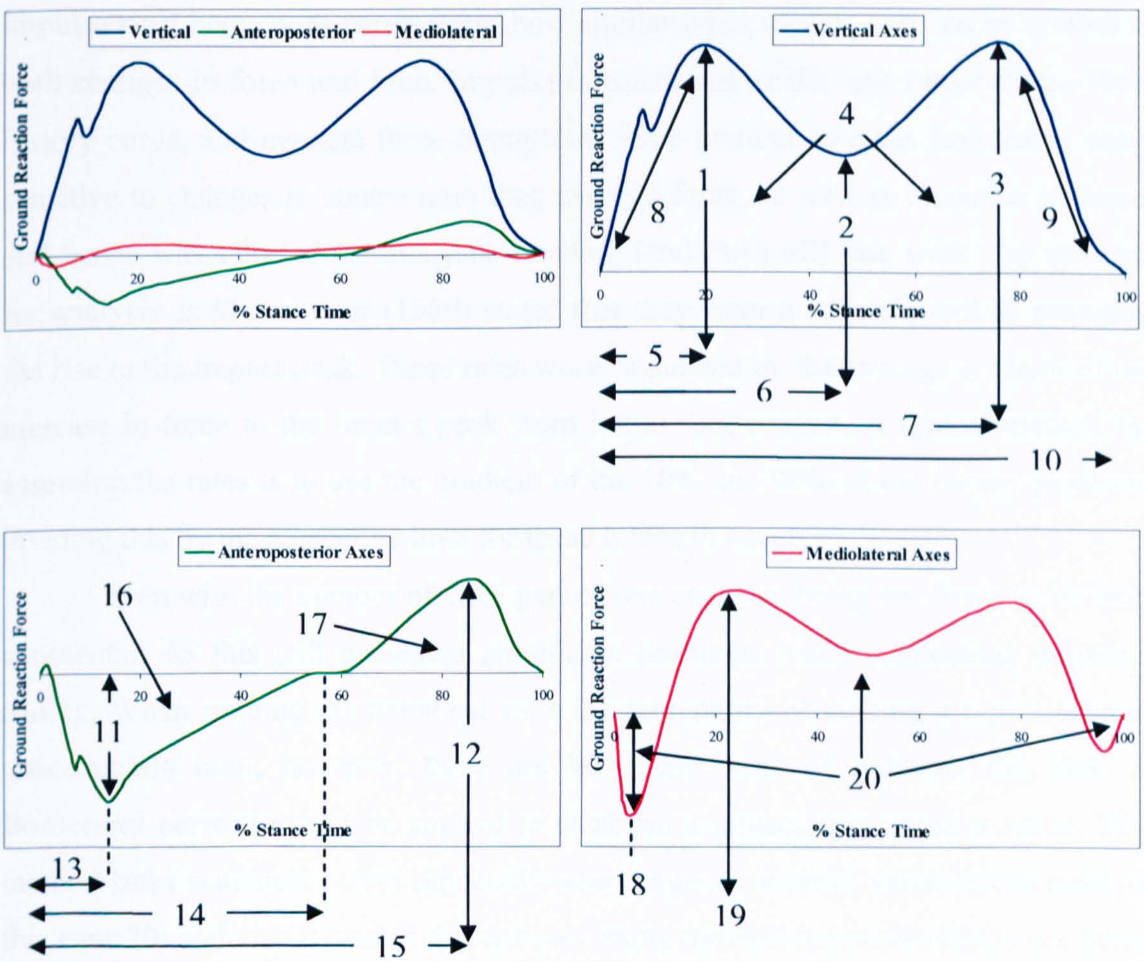


Figure 3.19: GRF parameters selected for analysis.

As can be seen above 20 key GRF parameters from all 3 axis of force were chosen for analysis in all the biomechanical studies of this thesis. The selected parameters were derived from reviewing the literature both regarding gait analysis in general and the relevant load carriage literature. Also, pilot studies helped to determine which parameters were reliable and repeatable thus giving the best quality of data. These pilot studies highlighted that, as reported in the literature previously, the mediolateral axis is the most variable and liable for the greatest individual differences (Cavanagh, 1987; Munro et al, 1987). Both Bates et al (1983) and Hamill and McNiven (1990) separated the mediolateral axis in percentage of stance to calculate force and impulse. For current work it was decided not to adopt this methodology as the pilot study showed high variability in the mediolateral data. The most stable mediolateral parameter was the mediolateral impulse. Other studies investigating the effect of changing gait on GRF patterns have used average vertical, braking and propulsive force instead of the selected vertical, braking and propulsive impulse used here. Both parameters show similar types of data and can be related to both changes in force and time. Impulse is calculated as the area under Force-Time history curve, and average force being total force divided by time. Impulse is more sensitive to changes in stance time than average force, as well as increases in force, and hence was selected for analysis. Loading (and Push-off) rate were also selected for analysis as Munro et al (1989) stated that they were a valuable tool in assessing the rise to the impact peak. These rates were calculated by the average gradient of the increase in force to the impact peak from initial foot contact. A typical method for assessing the rates is to use the gradient of the 10% and 90% of the impact peak and dividing this by the respective time for these forces to occur.

Even with the number of GRF parameters analysed being cut down to 20 from a potential 45 this still presented significant problems when conducting statistical testing. When running 20 statistical tests the probability of making a type I error is unacceptably high; however, there are legitimate ways of reducing this risk. A Bonferroni correction can be applied to establish a protected criterion p value. This method lacks statistical power especially when large numbers of variables are used (in this case 20) and also it cannot discern how many dimensions of variability are being tested. The second option is to run a multivariate analysis of variance (MANOVA) this test reduces the familywise error rate and negates the need for conservative Bonferroni corrections (Brace et al, 2000).

Twenty GRF parameters were selected for the analysis for the general effect that carried load produces. From this 8 major GRF parameters were derived, these were selected due to their overall importance and ability to link them to specific events, e.g. an increase in the magnitude or number of impact peaks is strongly linked to the development of overuse injuries of the lower limb (Cavanagh and LaFortune, 1980; Nigg et al, 1987; Keller et al, 1996; Knapik, 2001). The 8 major parameters selected were: Impact Peak; Force Minimum; Thrust Maximum; Vertical Impulse, Maximum Braking Force; Maximum Propulsive Force; Mediolateral Impulse and Stance Time (figure 3.20). Other parameters were excluded due to their correlations to selected parameters. For example, results from the pilot study showed that the time to certain events was very strongly linked to stance time, therefore an increase in stance time lead to increases in the other time parameters. Also, the braking and propulsive impulses were again strongly linked to the maximum braking and propulsive force. Vertical impulse was however included as the vertical parameters impact peak, force minimum and thrust maximum can all change independently of each other, for example an increase in impact peak and decrease in force minimum is common. The mediolateral impulse was shown to be the most reliable of the mediolateral axis parameters and hence chosen as one of the major parameters. The 8 major GRF parameters selected were analysed when the potential observed differences were likely to be smaller in size and potentially lost with a more general statistical test. Bonferroni corrected multiple ANOVAs and t-tests were conducted with this data.

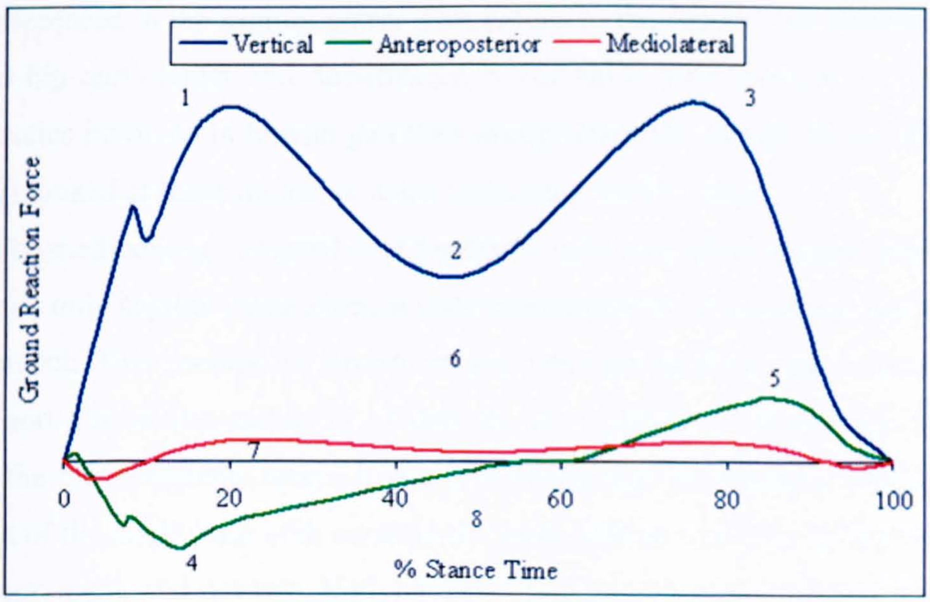


Figure 3.20: Major GRF parameters selected: 1 – Impact Peak; 2 – Force Minimum; 3 – Thrust Maximum; 4 – Maximum Braking Force; 5 – Maximum Propulsive Force; 6 – Vertical Impulse; 7 – Mediolateral Impulse; 8 – Stance Time.

Table 3.2: Definitions and how major GRF parameters were calculated.

Parameter	Axis	Calculated
Impact Peak	Vertical	Max of 1st peak during heel strike
Force Min	Vertical	Min of trough during stance
Thrust Max	Vertical	Max of 2nd peak during to-off
Max Braking Force	Anteroposterior	Max (-ve) force during heel strike
Max Propulsive Force	Anteroposterior	Max (+ve) force during toe-off
Vertical Impulse	Vertical	Area under vertical force curve
Mediolateral Impulse	Mediolateral	Area under mediolateral force curve
Stance Time	Time	Time foot is in contact with ground

3.6.2 Kinetic Parameters Measured

Kinetic parameters of the lower limb are taken at the ankle, knee and hip. The power and moments produced at these joints are derived from both the force plate and angular data. A moment is defined as the force applied to a rotational system measured in Newton-meters (N.m), or in this case the turning force produced by the joint. Power is work done per unit time of the joint, measured in Watts (W). The most popular kinetic parameters measured are the moments of the ankle, knee and hip usually measured in the sagittal plane. This relates to the flexion and extension of the knee and hip and planter and dorsiflexion of the ankle joint; not only are these the main muscles involved in human gait they also produce the largest forces. Harman et al, (2000) looked at these moments when evaluating load carriage.

The methodology adopted for Chapter 10 used a bilateral 3D gait analysis, this enabled not only sagittal plane kinetics (and kinematics) to be measured, but all 3 axes of movement. This method is almost unique amongst load carriage biomechanical studies, and allows the gathering of data in all 3 planes of movement. Table 3.2 outlines the measurements taken. It is worth noting that for example supination and pronation of the ankle joint both occur in the same axis so will only be represented by one measurement, and not two. Both moments and powers were collected for each of the joints in all 3 axis. Once the data were collected they was analysed and maximums, minimums and mean values were calculated. As well as calculating the overall mean for the moment or power produced at a specific joint it was deemed important to calculate the mean values for the different activities performed by the joint. For example the mean moment produced during pronation and during supination was calculated. Figure 3.21 shows an example of the moment produced at the ankle when walking with a load of 8 kg. Labelled on the graph are key aspects referring to maximum and mean moments produced in each of the 3 axis, these are described below.

1. Maximum planterflexion moment
2. Mean planterflexion moment
3. Maximum and mean dorsiflexion moment
4. Maximum pronation moment
5. Mean pronation moment
6. Maximum and mean supination moment
7. Minimum and mean negative alignment moment
8. Maximum and mean positive alignment moment

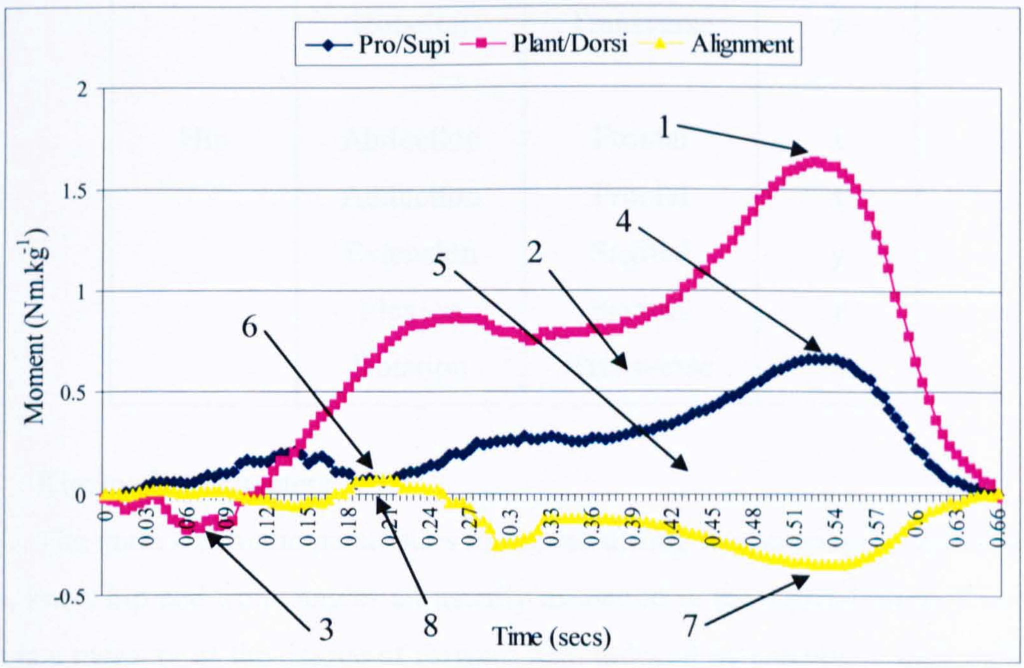


Figure 3.21: Example of ankle moment data collected in all three planes of movement.

Not included on figure 3.19 is the overall mean value for each of the axis. In total there are 15 parameters measured for each joint in terms of the moment produced. With 3 joints and both moments and power to consider, this totals 90 parameters for the kinetic data.

Table 3.3: Moments and powers measured with plane and axis of movement identified.

Joint	CODA Terminology	Plane of Movement	Axis
Ankle	Pronation	Frontal	x
	Supination	Frontal	x
	Planterflexion	Sagittal	y
	Dorsiflexion	Sagittal	y
	Alignment	Transverse	z
Knee	Valgus	Frontal	x
	Varus	Frontal	x
	Extension	Sagittal	y
	Flexion	Sagittal	y
	Rotation	Transverse	z
Hip	Abduction	Frontal	x
	Adduction	Frontal	x
	Extension	Sagittal	y
	Flexion	Sagittal	y
	Rotation	Transverse	z

3.6.3 Kinematic Parameters

The main kinematic parameters measured during load carriage research are the ankle, knee, hip and trunk angles all usually measured in the sagittal plane. The trunk angle is a measure of the degree of forward lean induced by carrying a backpack. It is well established that carrying loads on the posterior of the trunk induces forward lean and the greater the load the greater the forward lean (Kinoshita, 1985; Martin and Nelson 1986; Pascoe et al, 1997; Goh et al, 1998; Harman et al, 2000; Filaire et al, 2001; Attwells et al, 2006). Forward lean is a biomechanical response to load carriage and is an attempt to balance the moments of the external load being placed on the body and stabilise the body's centre of mass. Due to the well established effects of load carriage on trunk angle, this was not measured during this current thesis. Other parameters measured during load carriage studies have been the Craniovertebral angle, this gives an estimation of the position of the head on the neck (Raine and Twomey, 1997; Chansirinukor et al. 2001; Attwells et al, 2006). Also, the position of the centre of mass with load carriage has been analysed (Harman et al, 2000). Angles of the upper limb may also be of interest; however, these are more open to individual differences such as arm swing amplitude, method of rifle carriage and the inconsistent movements during the trial e.g. shuffling of the backpack.

During the research conducted for chapter 7 of this thesis, angles of the lower limb were measured, namely the ankle, knee, hip and pelvis angles. These 4 angles were not just measured in the sagittal plane, but all 3 axis encompassing flexion/extension, movement toward/away from the midline (centre) of the body and rotation (table 3.3). The range of motion of the angles were calculated from the maximum and minimum values, in total 12 kinematic parameters were analysed statistically. All angles were calculated from the left leg during the trials. This was due to complete stride (heel strike to heel strike) being in view with both Codas for the optimal length of time.

Table 3.4: Angles measured and description.

Joint	CODA Terminology	Description	Movement
Ankle	Supination	Roll onto outside of foot	Towards midline
	Pronation	Roll onto inside of foot	Away from midline
	Planterflexion	Lowering of toes	Decrease angle
	Dorsiflexion	Raising of toes	Increase angle
	Alignment	Direction toes point	Rotation
Knee	Varus	Knee bent inwards	Towards midline
	Valgus	Knee bent outwards	Away from midline
	Flexion	Bending of knee	Decrease angle
	Extension	Straightening of knee	Increase angle
	Rotation	Twisting of tibia	Rotation
Hip	Adduction	Moving leg towards body	Towards midline
	Abduction	Moving leg away from body	Away from midline
	Flexion	Raising of femur	Decrease angle
	Extension	Lowering of femur	Increase angle
	Rotation	Twisting of femur	Rotation
Pelvis	Obliquity	Side to side tilt of hips	Mediolateral tilt
	Tilt	Down or upward tilt of hips	Anteroposterior tilt
	Rotation	Twisting of hips	Rotation

3.6.4 Spatiotemporal Parameters

Spatiotemporal parameters are concerned with physical properties of the gait cycle – length and time. The most frequently used spatiotemporal parameters are stride length and stride time. However, the stride time in particular can be divided into other important aspects that describe the gait cycle. This includes the swing time, or length of time that one leg is in the air moving forward to position for the next heel strike. Single or double support times are the length of time only one foot or both feet are in contact with the ground (figure 3.22). Double and single support and swing time are more commonly expressed as a percentage of stride time. The percentage of the stride spent in single support is often called the 'duty factor'. Another stride parameter is the stride frequency of the number of strides per second (Hz).

Many of the above parameters measured are inter-related, those chosen for analysis for this thesis were: Stride time; % single support; % double support and stride length. Stride frequency was not included in the analysis as it is the inverse of stride time, and % swing was also excluded as this was directly related to % stance.

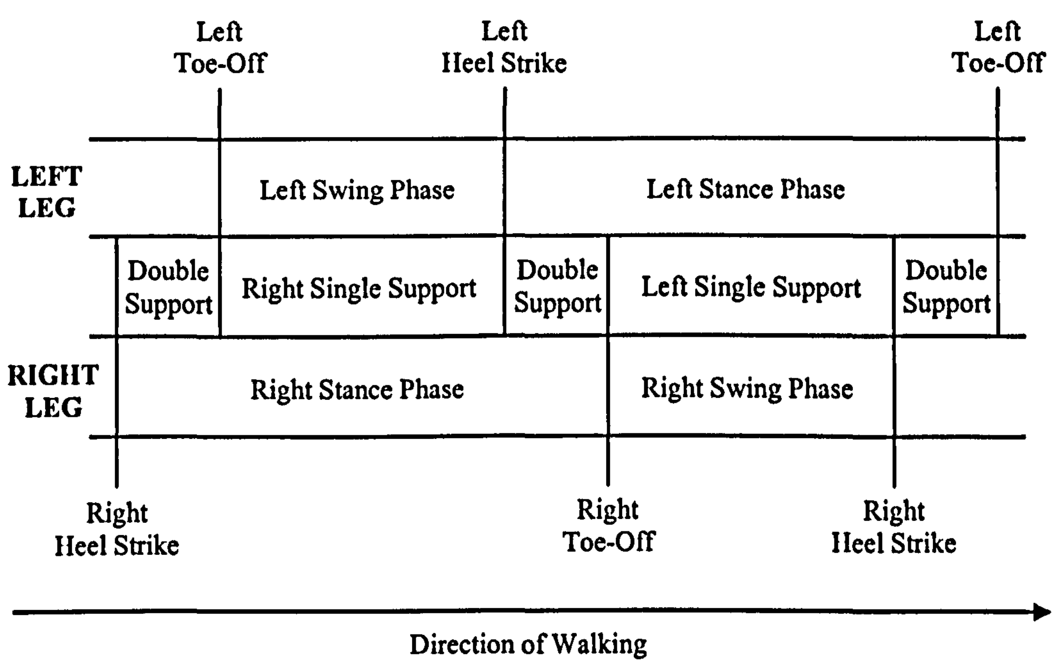


Figure 3.22: Illustration of spatiotemporal parameters measured.

3.6.5 Data Analysis

The biomechanical data were exported into Microsoft Excel from CodaMotion for processing in the form of text files. As mentioned previously the CodaMotion software has limited analysis capability outside of its own gait package and report generator. Numerous spreadsheets were written and compiled to calculate means, maximums, minimums, rates, times and distances. This processed data were then copied into different spreadsheets where 10-trial means and standard deviations were calculated.

GRF data were the most complex to process and due to the spreadsheet needed to calculate the loading and push-off rates in particular (figure 3.19). These rates were calculated from 10 to 90% of the impact peak. A macro was written to help determine the 10 and 90% values, from these loading and push-off rate can be calculated. The spreadsheet was setup to automatically normalise the GRF to Newton's of bodyweight (body or system weight multiplied by 9.81). From this normalised data, respective maximums, minimums, means and times were also automatically calculated. In addition to these data impulses were also calculated from the normalised data by calculating the area under the vertical GRF time-history and area within the braking and propulsive regions. Calculated data from this processing spreadsheet were then copied and pasted into another spreadsheet that calculated a 10-trial mean and standard deviation.

Kinetic data gathered were the maximum and mean agonist and antagonist movements of the ankle, knee and hip, as well as an overall mean for the joint. Data were collected and processed for both the joint moments and powers. The agonist and antagonist (e.g. planter and dorsiflexion of the ankle) were defined as the maximum and mean value above and below the x axis, or all the positive and negative numbers. A formula was written to calculate the respective positive and negative means. Kinematic and spatiotemporal data were simple to calculate as they consisted of finding one number from the array. Again the 10-trial mean and standard deviations were calculated, and these means are the values that are displayed in tables and graphs throughout this thesis.

3.7 Ground Reaction Force Pilot Study

3.7.1 Introduction

This pilot study was designed to assess what happened to ground reaction force (GRF) and spatiotemporal parameters with the carrying of military loads. Different masses and load carriage systems (LCS) were adopted, with both males and females involved in the study. The main aims of the pilot study were as follows: To assess reliability and validity of the force plate and test the equipment and protocol used. Also, determine which GRF parameters are most valuable for in depth analysis and evaluate potential differences between genders. Finally, to gain valuable experience planning and running trials, processing data and performing statistical tests. The data from the pilot study were collected in conjunction with another study being conducted by a colleague from the Load Carriage Research Group investigating the effect of gender on the kinematics of load carriage (Attwells, 2006). The kinetic data were collected in addition to the kinematics and only used for this pilot study.

3.7.2 Methods

Twenty participants (10 male (180.7 cm ± 7.2; 78.57 kg ± 8.4) and 10 female (167.0 cm ± 6.7; 68.8 kg ± 6.3)) were required to walk at a self-selected pace along a 7 m indoor walkway striking a force plate installed centrally and flush to the walkway, whilst carrying different military loads. The recruited participants all had previous experience with load carriage. Seven successful trials at each loading condition were collected with the force plate sampling at 200 Hz. The LCS was loaded with a percentage of bodyweight (BW) so the lighter the participant the less load they carried. The 4 loading conditions were as follows, Barefoot (shorts, t-shirt and replica SA80 rifle), Boot (as barefoot but with standard issue military boots), Webbing (as boot with the addition of PLCE waist webbing loaded to 7% BW) and Backpack (as webbing with '90 Pattern Bergen loaded to 33% BW).

3.7.3 Results and Conclusions

Conclusions drawn from the pilot study were that a fixed speed is needed. Results from the study show that when a self-selected walking speed is allowed there was a significant decrease in walking speed as load was added. A change in walking speed has been shown to alter stride parameters, which in turn may affect the angles of the knee and hip (Harman et al, 2000b). Data collected during the pilot study were normalised to both body weight and the weight of the load carried. This is an alternate and not frequently used method of data analysis. Results showed that there was a relative decrease in the normalised impact peak when the backpack was added. This was an unexpected result and may be as a result of protective mechanisms limiting the increase in force. More likely however is the decrease in walking speed seen with load as walking speed is directly linked to the GRF produced. Other results showed that as load was added there was a significant increase in stance time (or single support time) from 0.707 to 0.723 to 0.750 seconds for boot, webbing and backpack conditions respectively. This increase in stance time was very closely linked to changes in the other time parameters measured (e.g. time to impact peak or zero Newton's etc), suggesting that stance time is the dominant (and more frequently referenced) measure of time. No significant changes to any of the GRF parameters were observed with respect to gender, there was however a trend for females to exhibit a greater maximum braking force compared to males ($p=0.058$). This suggests that males or females could be used in the same group, or more likely due to ethical considerations that only males are needed to determine the effects of load carriage on gait.

Other more practical considerations were also concluded from the pilot study; the first being that the walkway was too short. It was found that although a natural gait pattern was maintained throughout, speed was more difficult to control especially with the heavier loads. Three strides before and after the force plate were originally achieved with the pilot study; however, when carrying heavy loads the first stride is usually more tentative and less stable. The walkway was subsequently lengthened to 8.4 m during future studies allowing 5 strides before the force plate and 4 strides after. The rifle condition was a suitable control as a rifle was carried in all the loading conditions. The barefoot condition was excluded from any analysis and would only be useful if comparing the effect of wearing military boots.

In the main biomechanical studies of this thesis data were normalised to either bodyweight or bodyweight plus rifle. This method of normalising data can only be used if the same load is carried by all of the participants. With this pilot study a percentage of body weight was carried, in reality this was achieved by participants falling into one of 3 load categories; either total carried load of 24, 28 or 32 kg. Hence normalising by bodyweight would not be accurate as each category had a weight range of 10 kg. This method of normalising to body weight can only be conducted when the same load is carried by all participants or if a percentage of bodyweight is very accurately calculated. Even if this is done problems will still arise with changing the load distribution of the LCS. With only two different loads used, along with a control, and loads of 7% and 40% bodyweight carried more load increments are needed to accurately predict GRF produced as well as assessing the proportionality of the potential changes in gait with load carriage.

Further issues regarding the equipment and protocol were also highlighted. The force plate produced reliable and repeatable data, with little drift occurring. To ensure this is maintained the force pate has to be reset between each trial, or at least every 5, so the system is zeroed. Also, the force plate needed to be set to the high threshold ensuring that the force plate can collect data up to 2.5 kN in the vertical axis and up to 250 N in the anteroposterior and mediolateral axis. Vigilance needs to be maintained to ensure the force plate does not 'top out' particularly in the anteroposterior axis. The four force sensors of the force plate each measure a quarter of the total force, so if the foot lands close to one of these sensors the anteroposterior force measured by an individual sensor may be above it's 62.5 N threshold. If this occurs then a red light will display indicating that one of the sensors has overloaded in any of the three axis, this trial should be re-ran as the data may be compromised. The Coda Mpx30 used to collect the force data in conjunction with the force plate had sufficient range of sampling frequency of up to 800 Hz, and the CodaMotion software records data in an easy to use and exportable format. Other issues refer to the health and safety of participants. Cables are potentially dangerous as they are needed to link up the force plate, Coda and computer. These cables must be kept off the walkway at all times and where possible under cable safety strips. Although the period of load carriage is short adequate rest needs to be given between trials and if necessary the removal of the LCS between conditions. Finally, conducting this work has allowed valuable experience to be gained in collecting and processing kinetic data and also in statistical testing.

3.8 Comfort During Load Carriage Measured Using Subjective Ratings

Previous research in the literature regarding the use of subjective ratings to assess comfort and injury during load carriage is outlined in Chapter 8, section 8.6. Work conducted for chapters 9, 10 and 11 of this thesis involved the collection of subjective data by 3 different means: Comfort ratings, interviews and questionnaires. The following section will outline how these methods were used and why the selected approaches were adopted.

3.8.1 Comfort Ratings

The measurement of subjective responses can be achieved by using various different types of scales, these include: Ordinal Scale – this uses a simple rating scale usually from 1 to 5 or 7, with ratings ranging from, for example, very comfortable to very uncomfortable. Visual Analogue Scale (VAS) – this is a line with a minimum rating at one end (e.g. very comfortable) and maximum at the other (very uncomfortable). The participant then indicates the perceived intensity by placing a mark on the scale. Interval Scale – Intensity is matched to a number on a predetermined list.

Comfort data for this thesis was collected by using a 5 point (table 3.4) comfort scale to rate the comfort of different musculoskeletal regions. Subjective data collected for Chapter 9 (interview study) assessed comfort every 15 minutes at the shoulders, back, hips and feet. This was an overall comfort with no sub-zones defined. The two questionnaires studies that were completed (Chapter 9 and 11) also asked military participants to state the comfort of regions of the upper and lower limb and also at the back. These also used the 5 point comfort scale presented in table 3.4.

Table 3.4: Scale used to rate comfort.

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

The comfort scale in table 3.4 was selected as it has been thoroughly validated by work completed by Martin (2001). Martin wanted a scale that was easy to follow as it would be used by participants who would be carrying heavy loads and a complex scale would not be appropriate. Ordinal scales like this can be either one or two way. Two way scales are more common as they assess both positive and negative aspects, this was deemed unnecessary with load carriage as carrying between 20 and 40 kg would never be termed very comfortable. This enabled the scale to be reduced in size and more specific focus given to the inevitable negative aspect of load carriage. Even though the scale was only one way, in the discomfort direction, it was always referred to as a 'Comfort Scale' and not 'Discomfort Scale'. Calling it a discomfort scale may give the preconception that the activity undertaken will be uncomfortable, thus affecting the potential bias of the test. The 5 point comfort scale has been used extensively in preceding load carriage research conducted by Jones (2005) and Attwells (2006).

3.8.2 Interviews and Questionnaires

Interviews and questionnaires are widely used methods aimed at 'extracting' information from people. These methods can be used individually or in combination in a multi-method approach, producing a more comprehensive assessment. Subjective data analysis aims to gather information regarding participants' knowledge, behaviour, beliefs and attitudes. The following review of subjective methods has drawn upon several standard texts (Oppenheim, 1992; Robson, 1993; Sinclair, 2005).

An interview is a conversation that is 'initiated by the interviewer for the specific purpose of obtaining research-relevant information and focused by him on content specified by research objectives of systematic description, prediction or explanation.' (Cannel and Kahn, 1989; cited by Robson, 1993, p 229). An interview is considered a flexible and adaptable method of unearthing information. It has been suggested that during the 'exploration phase' of a research project, which usually occurs at the beginning of a project, interviews are probably the best way to commence this activity. Interviews can be either fully-, semi- or unstructured. The first two are termed respondent interviews, where the interviewer remains in control of the direction of the interview throughout. Unstructured interviews are informant interviews, with the prime concern being the interviewee's perception. The benefits of conducting interviews are that interesting point raised can be followed up and underlying motives and beliefs investigated. Non-verbal communication can also be assessed. Finally, the interviewer can accelerate, direct or improve the quality of information flow. Negative aspects of the interview are that answers given by numerous participants are often difficult to group into certain responses, even though the same question may have been asked. Interviews are time consuming, both in terms of collecting and analysing data. Also, the information gained from interviews is dependent on the interviewer and interviewee. A poor interviewer may not obtain the relevant information from the participant, or may impart bias on their responses. If the interviewee is not comfortable with the situation, or generally not responsive to the process then limited information can be gained. Finally, statistical analysis from interview responses can be very difficult, if not impossible.

Self-reported questionnaires are appropriate where it is desirable to collect information from large numbers of people, at relatively low cost and relatively quickly. If the questionnaire has been well structured then the time needed to code and analyse the responses can be very short. A good questionnaire will be easy to complete and understandable by the participant, while using correct language and terminology. Poorly written and presented questionnaires may lead to confusion to what is actually being asked, or minimal responses given. Questions are also open to misinterpretation. Too many open-ended questions may lead to the questionnaire taking too long to complete and inaccurate or curtailed answers given. However, insufficient options may again lead to inaccurate answers being given by participants. In order for good quality data to be attained numerous factors need to be taken into account, such as; the use of open- and closed-ended questions, specific or general questions, use of forced choice statements, a measurement (or scale) of intensity, the offering of 'no opinion' or 'neither' option. The most important principal with questionnaires is to ask the questions that you want answering. A good guide line is to structure questionnaires around the idea of: how many, how often and how much (Oppenheim, 1992; Robson, 1993; Sinclair, 2005).

3.9 Conclusion

Data collection for the biomechanical studies were conducted using a Kistler force plate and Coda Motion Analysis System. Both of these systems offer reliable and valid methods for gait analysis. Collecting force data using the Coda Mpx30 does present certain limitations compared to using an external A/D converter. These limitations are confined to limited post data collection processing, and not affecting the collection of the kinetic data itself. The use of the Coda Cx1 and Mpx30 in conjunction with the force plate and Coda gait package to collect 3D, bi-lateral gait analysis data is again reliable and valid. Gait analysis will always pose potential errors, these have been identified in this methodology chapter and efforts will be made to reduce and eliminate these risks.

The use of subjective ratings to assess body comfort during load carriage has been thoroughly tested in the scientific literature. Specific to this thesis the 5-point ordinal scale used to rate comfort has tested and validated rigorously as it has been used in previous military load carriage work conducted at Loughborough University (Martin, 2001; Jones, 2005; Attwells, 2006). The interviews and questionnaires were written, piloted and conducted with constant reference to standard texts for the collection of subjective data. These methods were again to be considered both valid and reliable.

Chapter Four – Effect of Heavy Military Load Carriage on GRF Parameters[1,2]

4.1 Introduction

The biomechanics of human gait during load carriage and in particular analysis of ground reaction forces (GRF) offers an important insight into the prevention of injuries to the lower limb. Reviewing the literature regarding the kinetics of load carriage, as presented in chapter 2, revealed some important questions relevant to fully understanding the effect that military load carriage has on GRF parameters. These include: Do GRFs increase proportionally when heavy loads are carried; does shifting the load distribution alter the GRFs produced? Does rifle carriage modify basal gait patterns? Are changes observed in the mediolateral axis of GRF? Throughout this thesis these questions will attempted to be answered.

This study was the first biomechanical study conducted for this thesis. Its primary aim was to examine the effects of progressive 8 kg increments in carried load on GRF parameters, and therefore establish base-line GRF data for load carried using the U.K '90 Pattern load carriage system (LCS), as described in chapter 3. The study design allowed other factors to be investigated including the effect of changing the load distribution and also the potential effects of rifle carriage on GRF parameters. To achieve these aims a laboratory based study was adopted where kinetic data were collected from 8 conditions in which various loads between 0 and 40 kg were carried. The following hypotheses were tested:

H_1: Load carriage of up to 40 kg will increase vertical and anteroposterior GRFs proportionally to applied load.

[1] *Work from the following chapter published in Gait & Posture, October 2007.*
[2] *Work from the following chapter presented at Ergonomics Society Annual Conference, March 2005.*

H_0: Load carriage of up to 40 kg will not increase vertical and anteroposterior GRFs proportionally to applied load.

H_2: Changes to the mediolateral axis of GRFs will not occur during load carriage.

H_0: Changes to the mediolateral axis of GRFs will occur during load carriage.

H_3: Changing the distribution of carried load and carrying a rifle will modify basal gait patterns.

H_0: Changing the distribution of carried load and carrying a rifle will not modify basal gait patterns.

4.2 Background

Military mission requirements often depend on personnel mobility. In these situations soldiers carry their own equipment, usually in a backpack (Bergen) and webbing, so forming a LCS. A rifle will also be carried on most occasions when marching. The study of GRF during load carriage provides researchers with relevant information about the mechanisms of gait and provides a measure of the impact force on the foot. For these reasons it is extremely valuable in aiding the understanding and prevention of lower extremity injuries (Harman et al, 2000). Research into the effects of running on GRF have indicated a positive association between impact force and lower limb overuse injuries, such as stress fractures of the tibia and metatarsals and knee joint degradation (Cavanagh and LaFortune, 1980; Nigg et al, 1987; Keller et al, 1996).

Research investigating the effect of load carriage on GRFs and gait is not widely represented within the literature. Early research was undertaken in 1983 by Kinoshita and Bates, who studied the effects of carrying either 20 or 40% of bodyweight in two different LCS on selected GRFs parameters. Proceeding this work the majority of research had been conducted in association with the U.S military at the Natick Soldier Systems Center. Conclusions drawn from the literature confirm, that as would be expected, both vertical and anteroposterior GRFs produced during gait increase when load is applied to the body. This is shown consistently with the vertical parameters of GRFs (including impact peak, force minimum, thrust maximum and vertical impulse) and anteroposterior parameters (braking and propulsive maximums and impulses). However, the proportionality or rate of this increase has been debated within the literature. The majority of research suggests the increase in vertical and anteroposterior GRFs to be directly proportional to the applied load. Other studies suggest that protective mechanisms are activated, such as an increase in double support, decreased walking speed or altered joint kinematics, when carrying heavy loads in an effort to reduce stresses placed on the lower extremities. Also, changes in the mediolateral axes of GRFs have been found to be insignificant or not even reported. Finally, alterations to the temporal parameters of gait with load carriage (such as single and double support times, stride length and frequency and preferred walking speed) have again led to varied conclusions within the literature, especially when comparing free to fixed walking speeds.

4.3 Methodology

4.3.1 Participants and Equipment

Fifteen male participants volunteered for the study (mass 83.2 kg ± 10.0 S.D., height 178.8 cm ± 5.4, age 27.8 years ± 7.0). To comply with the University ethical approval (R04/P57) each participant had to weigh over 70 kg. This was in order for the % bodyweight being carried to be deemed acceptable, participants were also required to have previous experience of carrying heavy backpacks. All participants were rear-foot strikers, ensuring a heel strike was observed during their gait. A verbal and written explanation of the study was given, after which a health screen questionnaire was completed. Informed consent was obtained from all participants before commencing the trial. A Kolmogorov-Smirnov test was conducted to ascertain whether the participants used were drawn from a normal population. Normality of distribution was assumed taking into account the ethical limits placed on selection, participants being at least 18 years of age and 70 kg or over. Testing sessions were conducted from Monday 9th August to Monday 16th August 2004, in the Load Carriage Lab in the James France Building at Loughborough University.

Kinetic data were collected with a Kistler force plate in conjunction with a Coda Mpx30 motion analysis system, as outlined in section 3.4.1. The load was carried using a standard issue UK '90 Pattern Short Back Bergen and PLCE waist webbing, which when worn together form a LCS. An un-weighted replica SA80 assault rifle was also carried in certain conditions, weighing 2.1 kg. Participants wore standard issue military leather boots and woollen socks throughout the duration of the study, they were also asked to wear comfortable non-restrictive clothing. For further details on LCS, rifle and other personal equipment refer to section 3.2. In the final condition (LCS 3 in table 4.1) an additional 8 kg was added to the LCS in one of three ways designed to replicate methods that extra load may be carried by military personnel. Load was added in the form of a weighted cardboard tube (simulating a light antitank weapon (LAW)) carried either across the top of the pack (LAW) or over the right shoulder (Side), or in the form of a weight block (Top) (figure 4.1).

Top – 8 kg added in a 30 x 20 x 20 cm rectangular block. This weight was added directly into the top of the Bergen and simulated radio equipment or extra ammunition that may need to be carried during operations.

Law – A weighted circular cardboard tube 88 x 13 cm weighing 8 kg, this was added under the flap of the Bergen and protruding at each side. This method of carrying a LAW is common, and is likely to make the carrier less stable.

Side – The LAW was carried unilaterally on the right side of the body, creating an unbalanced load.

Figure 4.1: Load used in LCS 3. Top, LAW and side (from left to right respectively).

4.3.2 Protocol

Each participant completed all 8 conditions (table 4.1), with 10 successful trials in each condition. The force data were sampled at 400 Hz and the target walking speed throughout was 1.5 $m.s^{-1}$ (± 5%). A trial was deemed successful if the speed was attained, the participant's dominant foot struck cleanly on the force plate and if a natural gait pattern was maintained. Participants were also encouraged not to target the force plate, as this may result in a change in stride patterns on approach to the force plate. To ensure participants had familiarised themselves with the load and walking speed an unlimited number of practice walks were allowed.

Table 4.1: Description of the conditions used during the study and total load carried.

Condition	Description	Load
Boot	Wearing non-restrictive clothes and military boots	0 kg
Rifle	As Boot, but carrying a replica SA80 rifle	0 kg
Webbing 1	As Rifle, with the addition of 8kg webbing	8 kg
Webbing 2	As Webbing 1, increasing load to 16 kg	16 kg
Backpack	As Rifle, with the addition of 16 kg Bergen	16 kg
LCS 1	As Rifle, carrying 8 kg webbing and 16 kg Bergen	24 kg
LCS 2	As Rifle, carrying 16 kg webbing and 16 kg Bergen	32 kg
LCS 3	As LCS 2, with addition of 8 kg in the Bergen	40 kg

In order to make the process of redistributing weight within the LCS more efficient and therefore reduce participant's time in the lab, certain conditions were grouped together in 'loading orders' (table 4.2). The order of which the participants completed these loading orders was randomised. This was in order to reduce the effect of fatigue from carrying the heaviest load last and other potential unforeseen effects. The exception to this rule being loading order 1 which was always completed first. This gave a gradual introduction to the testing procedure and enabled any technical difficulties to be overcome without the heaviest loads being carried (table 4.3). Participants were encouraged to start from the same starting position and with the same foot for every trial. This ensured the force plate was struck cleanly in a natural gait pattern and reduced the number of trials rejected.

Table 4.2: Loading order and conditions grouped.

Loading Order	Conditions
1	Boot & Control
2	Webbing 2 & Backpack
3	Webbing 1 & LCS 1
4	LCS 2 & LCS 3

In order to assess the potential effect that fatigue has on the GRFs of load carriage all participants who completed the heaviest loads (Loading Order 4) last were asked to complete an extra condition termed 'post trial'. This replicated the boot condition, with the intension of allowing comparisons between the two to be made and to assess potential affects of fatigue.

Table 4.3: Order of which participants completed the conditions.

Participant	First	Second	Third	Forth	LCS 3	Post Trial
1	1	2	3	4	Top	Yes
2	1	4	2	3	Law	
3	1	2	4	3	Top	
4	1	3	4	2	Law	
5	1	4	3	2	Top	
6	1	3	2	4	Law	Yes
7	1	2	4	3	Top	
8	1	4	3	2	Law	
9	1	2	4	3	Top	
10	1	4	2	3	Law	
11	1	3	2	4	Side	Yes
12	1	2	3	4	Side	Yes
13	1	3	2	4	Side	Yes
14	1	3	4	2	Side	
15	1	4	3	2	Side	

4.3.3 Parameters Measured and Data Analysis

Ground reaction force parameters were collected, normalised and means calculated (as outlined in section 3.6.5) for every condition. When assessing the effect of incremental increases in carried load on the kinetics of gait, all parameters were analysed. However, only the 8 major GRF parameters were analysed when assessing the other aims of the study, namely the effect of rifle carriage and load distribution. Reasons for this are explained in section 3.6.1.

The participants' kinetic data were normalised and expressed as Newton per unit body mass ($N.BM^{-1}$), allowing direct comparison between participants. Data from the boot condition were normalised to bodyweight (including clothes and boots). The other conditions were normalised to system weight (this is the weight of the rifle added to that of the participant).

4.3.4 Statistical Analysis

During the study data from 8 different conditions were collected, thus allowing numerous hypotheses to be tested. However, not all of the conditions were included in all aspects of the analysis. Table 4.4 shows which conditions were used to assess each of the aims of the study. The primary aim of the study was to examine the effects that small, incremental increases in load (of 8 kg) have on GRF parameters. For this reason the boot and backpack condition were excluded from this analysis (table 4.4). The reason for this was to eliminate two conditions where the same load was carried, 0 and 16 kg respectively. When no load was carried the rifle condition was selected over the boot condition, as the rifle condition was considered a more suitable control to the boot condition, as a rifle would be carried during the subsequent loading conditions. When 16 kg were carried the webbing 2 condition was selected over the backpack condition for analysis. This was again to eliminate the issue of having two conditions where the total load equalled 16 kg. During training and operations military personnel are more likely to carry 16 kg in their webbing alone than backpack alone; hence the reason for the selection of the webbing 2 condition in this section of the analysis. To determine the potential significant difference with carried load on GRF parameters a MANOVA was performed, with a Tukey post-hoc test between conditions. Significance was accepted at the level of $p<0.05$. Finally, regression analysis was undertaken to determine the association between the effect of load and the major GRF parameters.

Table 4.4: Study aims and corresponding experimental conditions.

Study Aim	Conditions Used
Effect of Load	Rifle, Webbing 1 & 2, LCS 1, 2 & 3
Load Distribution	Webbing 2 & Backpack
Rifle Carriage	Boot & Rifle
Effect of Fatigue	Boot & Post Trial

Other analyses conducted were on the effect of altering the load distribution and the effect of rifle carriage on gait (table 4.4). To assess the significance of potential differences between these conditions a Paired Student t-test was conducted on the 8 major GRF parameters. T-tests were also conducted to evaluate potential differences due to carrying the heaviest loads last (the boot and post trial conditions). Finally, a Tukey post-hoc test was run on the LCS 3 condition to determine if carrying the final 8 kg in the Top, Law or Side method changed the GRFs produced during gait. Again significance was accepted at $p<0.05$ for all of the above statistical tests.

4.4 Results

4.4.1 Effect of Load

Adding load to the '90 Pattern LCS in 8 kg increments had an overall effect to significantly ($p<0.05$) increase all of the major GRF parameters and majority of other parameters measured when walking at a fixed speed of 1.5 $m.s^{-1}$ (table 4.5). In addition to the overall effect of load, differences were highlighted by the post-hoc tests when considering each condition separately. All of the vertical and anteroposterior parameters increased significantly ($p<0.05$) with the addition of load in 8 kg increments. The stance time and mediolateral impulse parameters showed significant post-hoc increases between the majority of the loading conditions, as well as their overall effects. In addition to the MANOVA further analysis revealed significant ($p<0.001$) linear relationships between load and GRF (table 4.7).

4.4.2 Rifle Carriage and Load Distribution

Rifle carriage significantly ($p<0.05$) increased the impact peak, maximum propulsive force and mediolateral impulse while decreasing the force minimum compared to the boot condition (table 4.6). The effect of altering the load distribution of 16 kg by shifting it from the back to the hips, backpack and webbing 2 conditions respectively, altered GRF less dramatically then was observed with rifle carriage. However, the webbing 2 condition showed a significantly ($p<0.05$) greater impact peak and reduced stance time compared to the backpack condition (table 4.6). With exception to the increase in mediolateral impulse with rifle carriage of 7.5%, all other significant differences with GRF parameters observed were around 2 – 3%. These small but significant differences will be reviewed in detail in the discussion.

Table 4.5: Changes to mean GRF parameters with the addition of 8 kg increments of load from 0 to 40 kg, standard deviation in parentheses. Significance derived from the overall effect of load on selected parameter, * indicates significance difference as a result of load carriage. Major GRF parameters highlighted in bold. Forces measured in ($N.BW^{-1}$), Impulses (($N.BW^{-1}$).s), Rates in (($N.BW^{-1}$).s^{-1}) and Time in (s).

GRF Parameter	Condition						Level of Significance
	Rifle	Webbing 1	Webbing 2	LCS 1	LCS 2	LCS 3	
Impact Peak	1.226 (0.08)	1.327 (0.08)	1.443 (0.09)	1.541 (0.11)	1.650 (0.11)	1.763 (0.13)	p < 0.001 *
Force Minimum	0.602 (0.05)	0.644 (0.05)	0.697 (0.06)	0.741 (0.06)	0.795 (0.04)	0.854 (0.05)	p < 0.001 *
Thrust Maximum	1.205 (0.08)	1.326 (0.09)	1.434 (0.09)	1.571 (0.09)	1.645 (0.10)	1.721 (0.12)	p < 0.001 *
Max Braking Force	-0.287 (0.04)	-0.306 (0.06)	-0.334 (0.04)	-0.356 (0.06)	-0.368 (0.06)	-0.399 (0.07)	p < 0.001 *
Max Propulsive Force	0.222 (0.03)	0.246 (0.04)	0.266 (0.03)	0.289 (0.04)	0.300 (0.03)	0.321 (0.03)	p < 0.001 *
M-L Force Minimum	-0.073 (0.02)	-0.070 (0.02)	-0.071 (0.02)	-0.068 (0.02)	-0.071 (0.03)	-0.073 (0.02)	NS
M-L Force Maximum	0.082 (0.02)	0.094 (0.02)	0.088 (0.02)	0.094 (0.02)	0.091 (0.02)	0.091 (0.03)	NS
Vertical Impulse	1.076 (0.05)	1.191 (0.07)	1.288 (0.06)	1.411 (0.08)	1.492 (0.09)	1.595 (0.10)	p < 0.001 *
Mediolateral Impulse	0.043 (0.01)	0.048 (0.01)	0.050 (0.01)	0.052 (0.01)	0.053 (0.01)	0.056 (0.01)	p < 0.05 *
Braking Impulse	-0.087 (0.01)	-0.096 (0.01)	-0.105 (0.01)	-0.112 (0.01)	-0.119 (0.01)	-0.125 (0.02)	p < 0.001 *
Propulsive Impulse	0.057 (0.01)	0.067 (0.02)	0.070 (0.01)	0.080 (0.02)	0.081 (0.01)	0.089 (0.02)	p < 0.001 *
Loading Rate	9.649 (1.18)	9.996 (1.20)	10.790 (1.28)	10.889 (1.05)	11.611 (1.30)	12.339 (1.72)	p < 0.001 *
Push-Off Rate	12.464 (1.60)	13.426 (1.75)	14.500 (1.73)	15.030 (1.94)	15.749 (2.03)	16.334 (2.21)	p < 0.001 *
Time Impact Peak	0.136 (0.01)	0.143 (0.01)	0.143 (0.01)	0.151 (0.01)	0.151 (0.01)	0.153 (0.01)	p < 0.01 *
Time Force Minimum	0.313 (0.02)	0.322 (0.02)	0.329 (0.01)	0.337 (0.02)	0.341 (0.02)	0.342 (0.02)	p < 0.001 *
Time Thrust Maximum	0.516 (0.01)	0.520 (0.02)	0.522 (0.02)	0.527 (0.02)	0.527 (0.02)	0.530 (0.02)	NS
Time Max Braking Force	0.103 (0.01)	0.110 (0.01)	0.110 (0.01)	0.114 (0.01)	0.115 (0.01)	0.112 (0.01)	NS
Time Max Propulsive Force	0.568 (0.02)	0.576 (0.02)	0.578 (0.01)	0.585 (0.02)	0.583 (0.02)	0.584 (0.02)	NS
Time 0 N	0.377 (0.02)	0.378 (0.02)	0.386 (0.02)	0.387 (0.03)	0.396 (0.02)	0.388 (0.02)	NS
Stance Time	0.663 (0.02)	0.674 (0.02)	0.676 (0.02)	0.689 (0.02)	0.689 (0.02)	0.692 (0.03)	p < 0.01 *

TEXT BOUND INTO

THE SPINE

Table 4.6: Changes to selected mean GRF parameters for rifle carriage (boot and rifle condition) and load distribution (webbing 2 and backpack condition), standard deviation in parentheses. * indicates significant difference between conditions.

GRF Parameter	Condition		Level of Significance	Condition		Level of Significance
	Boot	Rifle		Webbing 2	Backpack	
Impact Peak ($N.BW^{-1}$)	1.203 (0.09)	1.226 (0.08)	$p < 0.05$ *	1.443 (0.09)	1.409 (0.10)	$p < 0.01$ *
Force Minimum ($N.BW^{-1}$)	0.622 (0.06)	0.602 (0.05)	$p < 0.05$ *	0.697 (0.06)	0.703 (0.05)	NS
Thrust Maximum ($N.BW^{-1}$)	1.212 (0.09)	1.205 (0.08)	NS	1.434 (0.09)	1.443 (0.09)	NS
Max Braking Force ($N.BW^{-1}$)	-0.286 (0.05)	-0.287 (0.04)	NS	-0.334 (0.04)	-0.338 (0.05)	NS
Max Propulsive Force ($N.BW^{-1}$)	0.215 (0.03)	0.222 (0.03)	$p < 0.01$ *	0.266 (0.03)	0.264 (0.04)	NS
Vertical Impulse ($(N.BW^{-1}).s^{-1}$)	1.082 (0.06)	1.076 (0.05)	NS	1.288 (0.06)	1.297 (0.07)	NS
Mediolateral Impulse ($(N.BW^{-1}).s^{-1}$)	0.040 (0.01)	0.043 (0.01)	$p < 0.05$ *	0.050 (0.01)	0.047 (0.01)	NS
Stance Time (s)	0.662 (0.02)	0.663 (0.02)	NS	0.676 (0.02)	0.687 (0.02)	$p < 0.001$ *

Table 4.7: Correlations for the 8 major GRF parameters with load ($p<0.001$).

Parameter	Pearson Correlation	Regression R^2	Coefficient	Constant
Impact Peak	0.883	0.780	0.013	1.223
Thrust Maximum	0.886	0.784	0.013	1.221
Force Minimum	0.854	0.730	0.006	0.598
Max Braking Force	-0.567	0.322	-0.003	-0.289
Max Propulsive Force	0.706	0.498	0.002	0.225
Vertical Impulse	0.922	0.851	0.013	1.084
M-L Impulse	0.338	0.115	0.001	0.044
Stance Time	0.419	0.176	0.001	0.666

4.4.3 Other Effects

The potential changes to GRF parameters as a result of carrying the heaviest loads last were also assessed. Changes were observed with two of the eight major GRF parameters, with the post trial condition exhibiting reduced forces compared to the boot condition. Parameters that differed significantly were the Thrust Maximum (1.258 to 1.210 $N.BW^{-1}$, boot to post trial respectively, $p<0.05$) and the Maximum Braking Force (-0.277 to -0.260 $N.BW^{-1}$, boot to post trial respectively, $p<0.05$). It is however important to note that only 5 participants were available for this analysis.

Finally, the effect of the changing method of load carriage in LCS 3 (top to LAW to side) revealed no significant differences for any of the GRF parameters measured. The post-hoc test did show a trend ($p<0.1$) for the Mediolateral Minimum to be greater when carrying the LAW over the shoulder (side) to when it was placed under the flap of the Bergen (LAW). This was however the only parameter close to acceptable levels of significance.

4.5 Discussion

The key finding from this study were that vertical and anteroposterior GRF parameters increased proportionally when heavy military loads were carried. As mentioned previously the proportionality of the increase in force with load has caused debate within the relevant literature. A more surprising result seen was the changes to gait patterns with rifle carriage. To the authors knowledge no study has been published which concerns the effect of military rifle carriage on either physiological or biomechanical parameters. The following section of this chapter will discuss in greater detail the results from this study and implications for these findings.

4.5.1 Effect of Load

Adding load in 8 kg increments increased all the major and numerous other GRF parameters measured (figure 4.2, table 4.5). This effect with increasing load has been described consistently within the literature (Kinoshita, 1985; Wiese-Bjornstal and Dufek, 1991; Tilbury-Davis and Hooper, 1999; Harman et al, 2000; Lloyd and Cooke, 2000; Polcyn et al, 2002). In addition to the increases in force observed, load carriage also resulted in an increase in stance time, this has also been seen with other research (Kinoshita, 1985; Wiese-Bjornstal and Dufek, 1991). Numerous studies (Kinoshita and Bates, 1983; Harman et al, 2000; Lloyd and Cooke, 2000; Polcyn et al, 2002) have found changes to mediolateral GRF parameters to be insignificant, with many others not reporting the data. Results from this current study challenge this as a statistically significant increase in the mediolateral impulse was observed with increasing load. The greater mediolateral impulse observed here may be linked to decreases in stability caused by the continual shift (in both the vertical and horizontal direction) of the body's centre of mass (CoM) away from its neutral position when load is added.

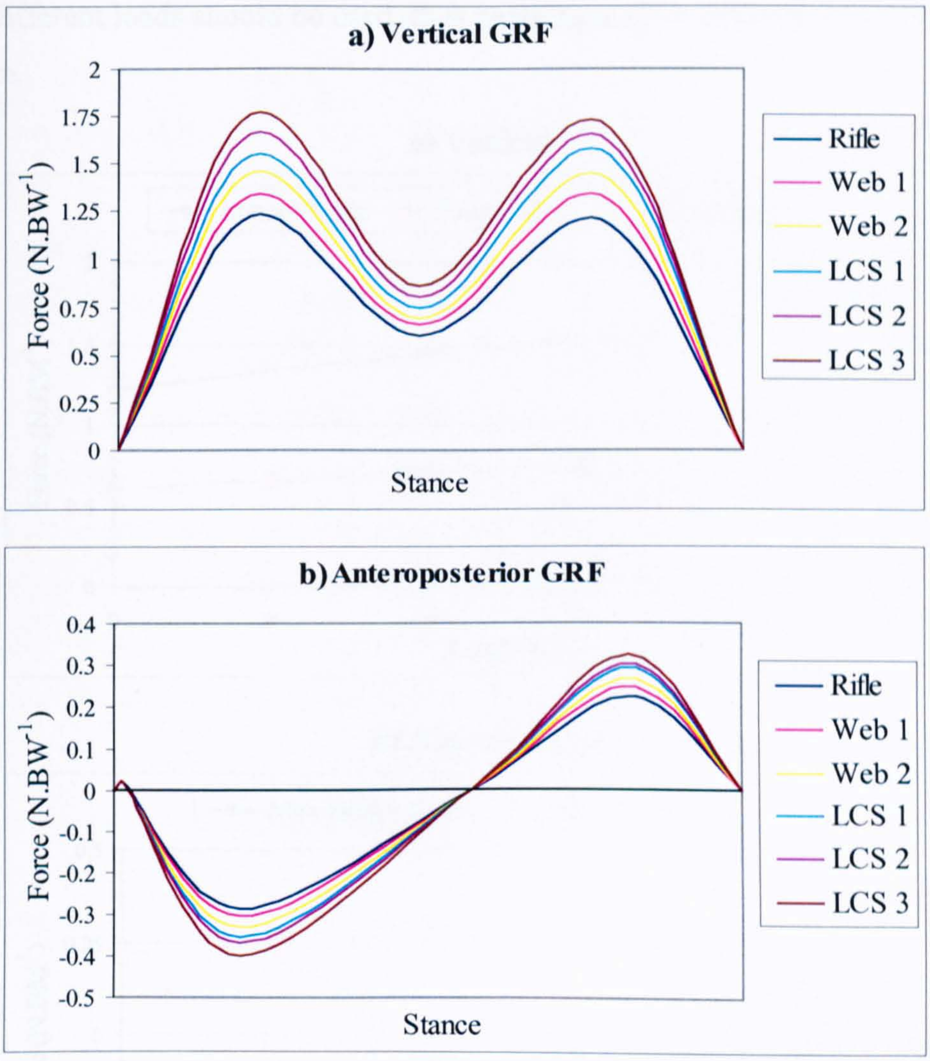
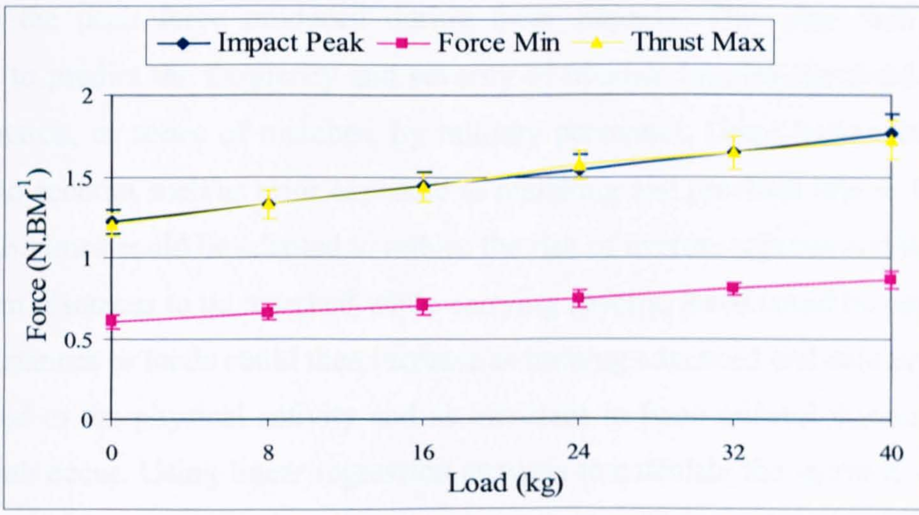


Figure 4.2: A graphical representation of the mean (a) vertical and (b) anteroposterior GRF produced when carrying load in increasing 8 kg increments.

As highlighted by the literature review, research is contradictory as to the proportionality of the increases in GRF parameters with applied load. Results from the present study support the hypothesis that increases in force with applied load represent a linear relationship when walking at 1.5 m.s^{-1}, even when heavy loads of 40 kg are carried. This is coincides with the findings previous research (Kinoshita, 1985; Holmes et al, 1999; Tilbry-Davis and Hooper, 1999; Lloyd and Cooke, 2000; Polcyn et al, 2002). This suggests that the increase in force observed is predominately due to the static effect of the load rather than changes to the acceleration of the system. Figure 4.3 shows this linear increase in vertical (a) and anteroposterior (b) forces against carried load. These plots suggest that only a small number of loads need to be tested to accurately predict vertical and anteroposterior GRF parameters. However, at least 3 different loads should be used, thus enabling a more accurate line of best fit to be drawn.

a) Vertical



b) Anteroposterior

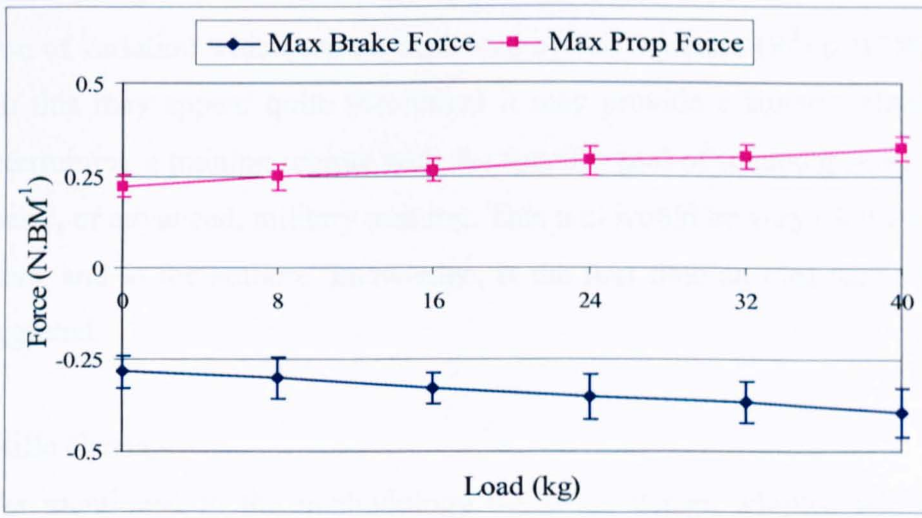


Figure 4.3: Linear increases in mean vertical (a) and anteroposterior (b) GRF parameters with increase in load.

High magnitudes or volumes of impact forces, like those experienced during load carriage or running, are a major risk factor for overuse injuries. In particularly stress fractures of the tibia and metatarsals, and knee joint problems (Cavanagh and LaFortune, 1980; Nigg et al, 1987; Keller et al, 1996; Knapik, 2001). Military recruits can cover up to 11 km per day, which is equivalent to around 9,000 impacts (Jones et al, 2001). For this reason it may be advantageous to be able to accurately predict the forces produced when heavy loads are carried over known distances. Establishing a dose-response relationship for distance marched and load carried may be feasible.

This would require the knowledge of the maximum stress or strain that can be placed on a bone or joint before stress fractures or joint degradation are likely to occur. It would then be possible to calculate the number of impacts made and accurately estimate the peak force produced during these impacts. This may then make it possible to predict the frequency and severity of overuse injuries sustained during a forced march, or series of marches, by military personnel. Other factors need to be taken into account such as prior exposure to marching and previous injury. However, training regimes could be adapted to reduce the risk of overuse injuries and theoretical maximum distances to be marched while carrying specific loads could be established. These distances or loads could then increase as training advanced and soldiers became more used to the physical activity and as increases in bone mineral densities of the lower limb occur. Using linear regression analysis to calculate the increase in impact peak force with load gave this equation: Impact Peak = (0.013 x Load) + 1.223. Load is measured in kg and the values for impact peak are expressed as $N.BM^{-1}$. The proportion of variation which can be explained by this equation (R^2) is 0.780 or 78%. Although this may appear quite theoretical it may provide a suitable starting point when determining a training regime with the specific goal of reducing stress fractures during basic, or advanced, military training. This tool would be very useful to military researchers, and to the authors' knowledge, is the first time an idea such as this has been suggested.

4.5.2 Rifle Carriage

As mentioned in the methodology the study design adopted allowed other factors of military load carriage to be analysed. The following section is concerned with the effect that rifle carriage has on GRF parameters. The carriage of a rifle has two effects, to restrict natural arm swing patterns and shift the body's CoM anteriorly (figure 4.4). The rifle used in this study was a replica SA80, the dimensions were equivalent to the actual rifle used by the UK military although the weight is around half, at 2.1 kg. Results from this study showed that carrying a rifle significantly ($p<0.05$) increased the impact peak, maximum propulsive force and mediolateral impulse compared to the boot condition. Also seen was a decrease in the force minimum in the vertical axis (table 4.6, figure 4.5).

a) b)

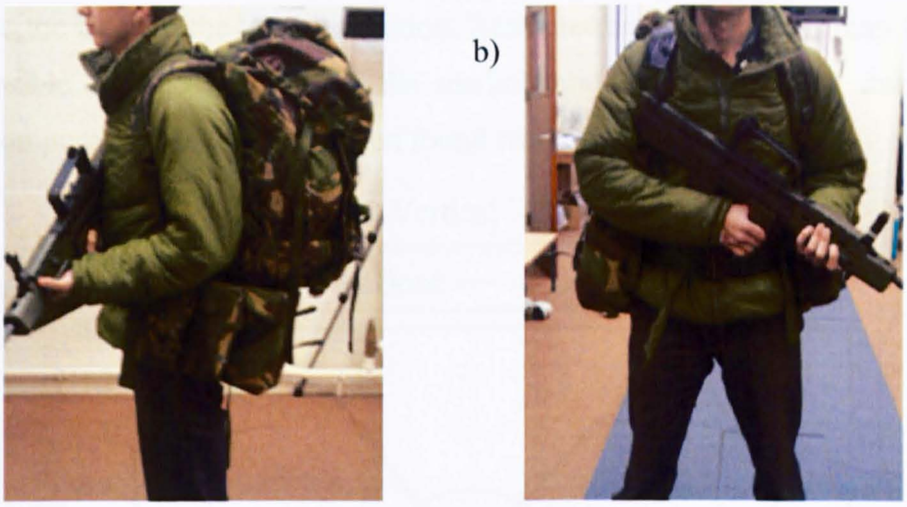
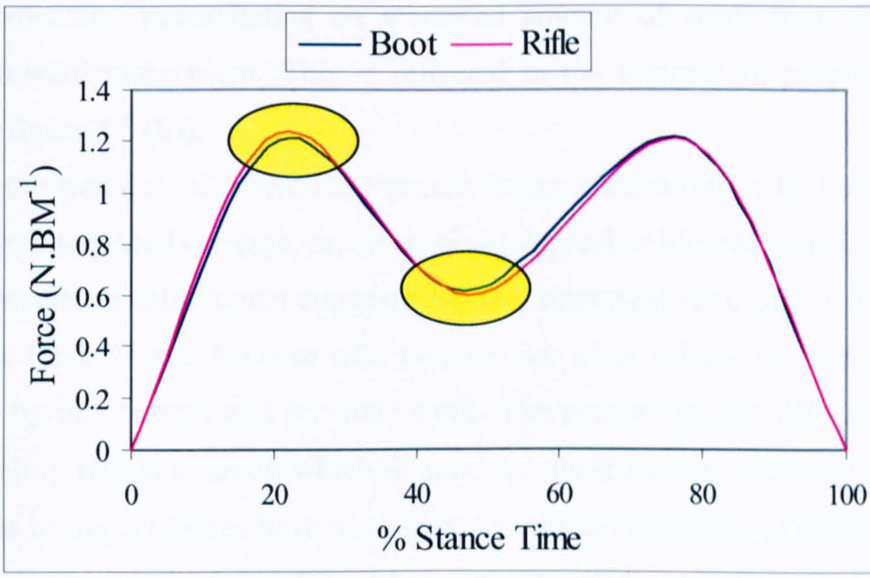


Figure 4.4: Rifle carriage during the LCS conditions. Panel (a) illustrates the forward shift in the CoM due to the rifle and (b) the restriction of the arms.

The small but statistically significant increase in impact peak observed (figure 4.5, (a)) may be due to the forward shift in the CoM as this generates increased force in the forward and downward direction at heel strike as a greater proportion of the mass is over the striking foot. In response, a lower force minimum may be observed as active momentum has been generated in the initial phase of the gait cycle facilitating forward propulsion (Hsiang and Chang, 2002). This was proposed by the authors to be in accordance with the inverse pendulum model described by MacKinnon and Winter (1993). Results from this study suggest rifle carriage induced such a response. Also observed was an increase in maximum propulsive force with rifle carriage. This is contrary to the inverse pendulum model, with other factors such as restricted arm movements thought likely to be the cause of this increase.

Rifle carriage also restricts arm movement, which may affect the GRFs produced. Research has showed that natural arm swing serves to counterbalance excessive horizontal rotation of the trunk, while also modulating vertical and horizontal excursions of the body's CoM (Elftman, 1939; Hinrichs, 1990; Eke-Okoro, 1997). If natural arm swing modulates the CoM, then restricted arm movement will impede this, and the CoM will be less stable. A greater range of motion of the CoM in the vertical direction whilst walking will lead to a greater downward acceleration of the body just before heel strike. This increased acceleration of the CoM may be another factor as to why the rifle carriage condition exhibits a greater impact force than the boot condition (figure 4.5 (a)). Natural arm movements have also been shown to stabilise the CoM in the lateral direction. Restricted arm movements may therefore be responsible for the increase in the mediolateral impulse exerted during rifle carriage compared to the boot condition found with this research.

a) Vertical



b) Anteroposterior

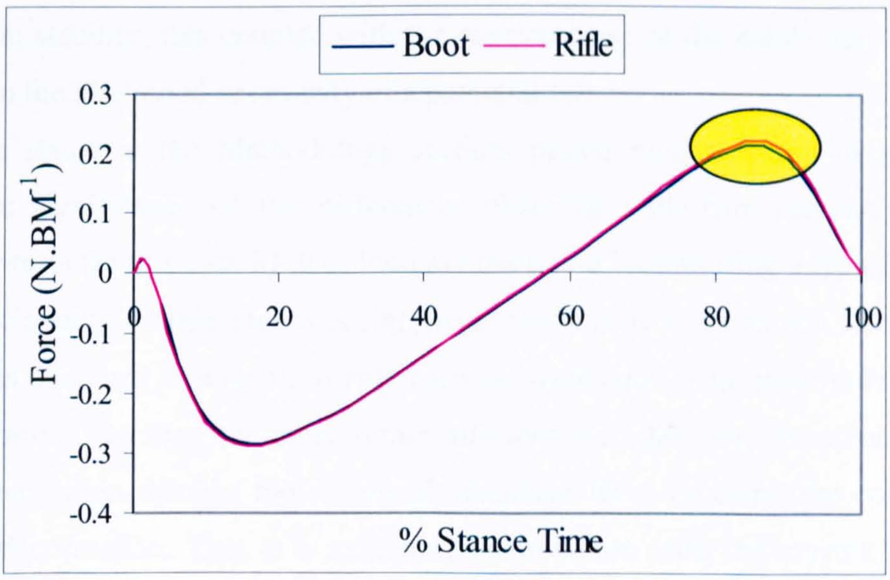


Figure 4.5: Mean vertical (a) and anteroposterior (b) GRF for the Boot and Rifle conditions against % stance time. Yellow highlighted areas depict where a significant difference in force was observed.

Studies have concluded that deliberate changes or restrictions to arm swing patterns reduce maximum velocity and stride length (Eke-Okoro, 1997). Of interest to the present study was the notion that restriction of arm movement influences the basal gait patterns and therefore may alter the GRF produced. One suggestion as to why the rifle condition displayed a higher maximum propulsive force to the boot condition is that natural arm swing increases the momentum produced by the upper body, so aiding the forward advancement of the CoM. Restricted arm movements limit this active momentum, necessitating an increased amount of work from the body to achieve forward momentum. This is reflected in the increase in propulsive forces observed (figure 4.5 (b)).

If the purpose of scientific research being undertaken is to investigate the effects of military load carriage, on either physiological or biomechanical parameters, results described in this chapter suggests that it is important for a rifle to be carried in addition to load. This is because rifle carriage has clear effects on gait patterns, as illustrated by this current and previous work. The possibility that rifle carriage may increase injury risk is a notion which is new. As stated earlier, increased volumes or magnitudes of impact forces have been linked to the development of overuse injuries, such as stress fractures of the tibia and metatarsals and knee joint degradation. Also, an increase in the mediolateral impulse, as seen with rifle carriage, is linked to a decrease in stability; this coupled with the restricted use of the hands may lead to an increase in the likelihood or severity of a potential fall.

As stated in the Methodology section, paired Student t-tests were used to derive the significance of the differences observed with rifle carriage. Running multiple t-tests (in this case 8) does increase the risk of committing a type I statistical error, by claiming a difference was significant when in fact it was not. However, the differences observed as a result of rifle carriage were smaller in magnitude then with load carriage. Therefore, the more subtle differences in gait may have been deemed insignificant when using a more general statistical tests, or using the conservative Bonferroni correction. This is a recognisable limitation with the current study and future methodologies address this issue. This results in care needing to be taken when viewing these results. However, with the vertical and anteroposterior parameters 93% of the participants tested reflected the trends seen in the mean values. For example with the impact peak 14 of the 15 participants exhibited a greater force at heel strike in the rifle compared to the boot condition. Further support for these results is given by the number of statistical differences observed. If 8 t-tests are conducted the chance of finding one significant difference by error is around 30%. Rifle carriage during this study produced 4 significant events out of 8. The likelihood of this happening by chance is just over 1%. For these reasons it is believed the difference observed during rifle carriage on GRFs to be actual events, and therefore important new findings for the area of research and certainly warrant further more detailed investigations.

4.5.3 Load Distribution

The different methods of load carriage used in the webbing and backpack condition represent a substantial shift in the distribution of the load. The webbing distributes load both anteriorly and posteriorly thus situating it closer in horizontal distance to the body's neutral CoM than the backpack. The Bergen is worn as a normal backpack, but without a functional hip belt, shifting the CoM posteriorly (figure 4.6).

a) b)

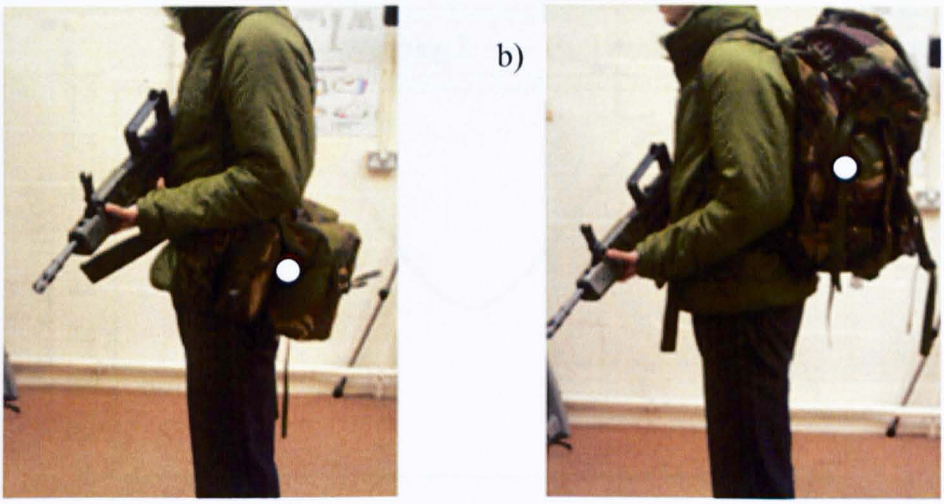


Figure 4.6: Webbing 2 (a) and Backpack (b) conditions with approximate CoM locations for the respective LCS marked with the white dot.

The 2 – 3% increase in impact forces observed in the webbing compared to backpack condition (table 4.6, figure 4.7), may be due to a larger component of the weight being over the striking foot at the time of initial contact. This is supported by previous research, suggesting that when the CoM is shifted anteriorly, the force at heel strike is increased (Hsiang and Chang, 2002). Other factors for the increase in impact peak with the webbing condition may be as a result of the difference in forward lean when carrying the two loads. Distributing load closer to the body's CoM has been shown to decrease forward lean and result in a more upright walking posture (Kinoshita, 1985; Harman et al, 1994; Attwells et al, 2004; Fiolkowski et al, 2006). Kinoshita (1985) suggest that a more erect walking posture, such as adopted when carrying the webbing, leads to more vertically orientated force vectors. This can be linked to greater forces being generated in the heel strike phase of gait and reduced forces from mid-stance through to toe-off.

Stance time was also slightly longer when carrying the backpack compared to webbing. This occurrence has been observed before (Kinoshita, 1985; Lloyd and Cooke, 2000), with backpack stance time showing a trend for being longer than those with the double pack (load distributed around the anterior and posterior of the trunk). A reason for this increase may be due to the extra time it takes to shift the CoM over the base of support and into the propulsive phase. Another mechanism for longer stance times with the backpack may be the need for extra stability when carrying load in the Bergen compared to the webbing, as load placed close to the body's CoM results in increased static stability (Schiffman, 2004).

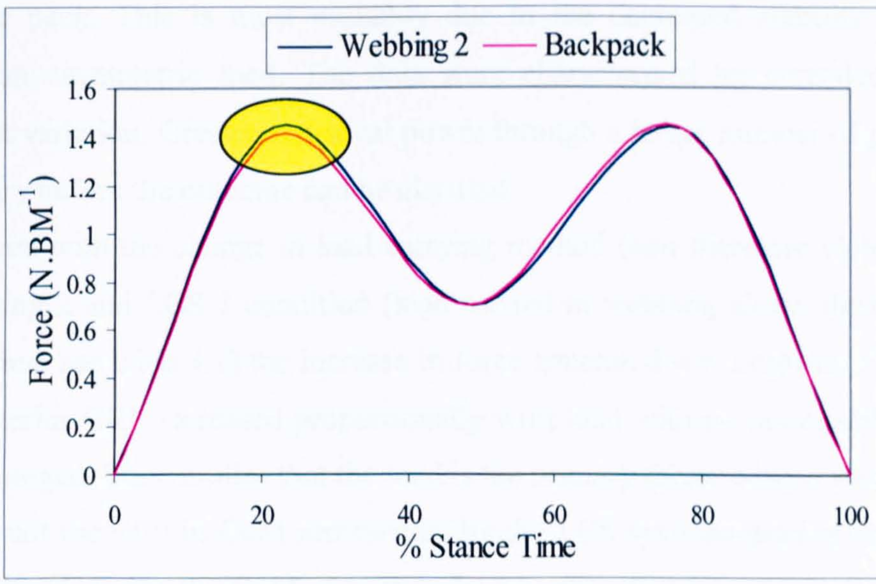


Figure 4.7: Mean vertical GRF for the Webbing 2 and Backpack conditions against % stance time. Yellow highlighted area represents where a significant difference in force was observed.

Again, as with the rifle carriage results, care needs to be taken when interpreting these results as multiple t-tests were run. However, the vast majority of participants showed the same trends as were represented by the means and two of the selected parameters showed significant changes between the two conditions.

4.5.4 Other Issues

As mentioned the effects of fatigue were evaluated with 5 participants that conducted the heaviest loads last performing a final 'post trial' condition. Significant differences were observed with thrust maximum and maximum braking force where the post trial condition exhibited reduced forces compared to the boot condition. This may be a method adopted by the body to conserve energy as less force is used to propel oneself forward (illustrated by reduced force at toe-off) and therefore to maintain speed less braking force is also applied. However, other factors are more likely such as changes to posture and physiological variables that were not measured.

The three load carriage methods adopted in the LCS 3 condition (top, LAW and side, figure 4.1) resulted in no observed differences to the measured GRF parameters. The low number of participants for each method may be a reason for this as each participant only undertook one of the methods. A trend was seen for increased mediolateral minimum force while carrying the LAW asymmetrically compared to across the pack. This is most probably due to the decreased stability caused by carrying an asymmetric load. The data were characterised by considerable inter-participant variation. Greater statistical power through a larger number of participants is necessary before the outcome can be clarified.

Even with the change in load carrying method (and therefore CoM) between the Webbing 2 and LCS 1 condition (load carried in webbing alone, then in Bergen and webbing, see table 4.1) the increase in force generated was uniform. Vertical and anteroposterior GRF increased proportionally with load with no discernible variation as LCS changed. This implies that the load is the primary factor behind the increase in force and not the shift in CoM represented by the LCS systems used here. However, substantially changing the CoM of backpacks by using double or front packs still has significant biomechanical effects (Kinoshita, 1985; Lloyd and Cooke, 2000; Harman et al, 2001). This aspect requires further attention.

Although walking speed was closely controlled changes to spatiotemporal parameters were not measured (e.g. swing and double support times, stride length and frequency). Changes to these parameters may also have affected the GRFs generated during load carriage. These factors will be investigated in future research conducted for this thesis.

4.6 Conclusions

This study aimed to examine the effects of progressive increments in carried load on GRF parameters. Results from the study suggest that both vertical and anteroposterior GRF parameters increase proportionally when load is added in 8 kg increments to a UK standard issue '90 Pattern LCS; this increase is observed even when heavy loads of 40 kg are carried, therefore Hypothesis 1 is accepted. Unlike many other studies increases in force generated in the mediolateral axes were also observed with increasing load, namely a statistically significant increase in mediolateral impulse with load. This finding leads to the rejection of Hypothesis 2. A new finding for this field of research is the effect of rifle carriage on GRFs. Rifle carriage caused an increase in the impact peak, maximum propulsive force and mediolateral impulse whilst decreasing the force minimum. These effects may be due to the forward shift in the CoM or more likely due to the restricted arm movements while carrying a rifle. This suggests rifle carriage has significant and important effects on basal gait patterns and may increase injury risk, thus Hypothesis 3 is also accepted. However, quantifying the increase in risk and mechanisms behind changes to gait patterns due to rifle carriage requires more research.

This initial study has provided base-line data for load carried in British military LCS. It also investigated the proportionality of the increase in GRF during heavy load carriage. Most interestingly however were the results from the rifle carriage and load distribution element of the study. These initial results highlight areas of interest for future work, while identifying unanswered future research questions. For example, what are the mechanisms behind the changes to GRFs as a result of rifle carriage? Is it mainly due to the forward shift in CoM or the restricted arm swing patterns with rifle carriage? Also, what effect does shifting the load distribution of LCS have on GRF patterns?

Chapter Five – Influence of Rifle Carriage on Kinetics of Human Gait[3,4]

5.1 Introduction

Chapter 4 presented initial findings concerning the effects of rifle carriage during encumbered gait. The study presented in this chapter follows on from this, with an aim of determining the effects that rifle carriage has on ground reaction force (GRF) parameters, and also establishing contributing factors to these effects. The effect of rifle carriage on gait has not been discussed in the available literature, and therefore its impact unknown. The most likely mechanisms behind the changes to gait observed in chapter 4 are either the restriction of natural arm swing patterns, or the addition of load to the anterior of the body, or a combination of both. In addition to investigating the effect of rifle carriage with no carried load, this study examined potential effects of rifle carriage while carrying a military load of 24 kg. As well as assessing the potential effects of rifle carriage on GRF the effects of load carriage were also re-examined. This was conducted to verify work conducted in Chapter 4 and validate results collected from the current study. To achieve these aims a laboratory based study using various rifle and loading conditions was employed to test the following hypotheses:

H_1: Rifle carriage will result in changes to GRF parameters.
H_0: Rifle carriage will not result in changes to GRF parameters.
H_2: Restriction of natural arm swing patterns will be the principal mechanism behind potential changes.
H_0: Restriction of natural arm swing patterns will not be the principal mechanism behind potential changes.

[3] *Work from the following chapter presented at the Injury Biomechanics Symposium, May 2006.*
[4] *Work from the following chapter accepted for publication in Ergonomics, in press.*

H₃: Rifle carriage while carrying military loads will show the same changes as observed when no load is carried.
H₀: Rifle carriage while carrying military loads will not show the same changes as observed when no load is carried.

5.2 Background

The effect of rifle carriage in military applications has received little attention in the published literature; this is in terms of either biomechanical or physiological effects. It is therefore unknown what influence carrying a rifle has on basal gait patterns. Also, if alterations are observed to what extent do these put carriers at an increased risk of injury (either overuse or acute injuries)? Rifle carriage has two main effects: to add load to the anterior of the body and to restrict natural arm swing.

The SA80 assault rifle, as used by British troops, represents a relatively small load of 4.4 kg, with the effect of producing a forward shift of the body's centre of mass (CoM). The majority of the load carriage literature is concerned with load that is carried on the back (in a backpack) or manually (in the hands either in front or by the side of the body). This research has shown that load carriage increases both vertical and anteroposterior GRF. Furthermore, results described in Chapter 4 showed load carriage to increase the mediolateral impulse. As well as shifting forward the CoM it is apparent that rifle carriage restricts natural arm swing patterns as caused by the fixed arm position required when carrying a rifle. Research has shown that the natural arm swing serves to counterbalance excessive horizontal rotation of the trunk, and modulate the vertical excursions of the body's CoM during walking. However, arm swing is not thought to contribute to the propulsion of the body. Restricted arm movements have also been shown to alter basal gait patterns by reducing preferred velocity and decreasing stride length.

5.3 Methodology

5.3.1 Participants and Equipment

Fifteen male participants volunteered for the study (mass 83.3 kg ± 13.3 S.D., height 184.4 cm ± 7.9, age 28.9 years ± 5.8). Ethical approval was granted by Loughborough University under the generic load carriage protocol (G03/P18).

Participants were either left or right foot dominant but all were rear-foot strikers. A verbal and written explanation of the study was provided, after which a health screen questionnaire was completed. Finally, signed informed consent was obtained from all participants before commencing the trial. Testing was conducted between 28th October and 21st December 2005 and took place in the Ergonomics Lab in the Wavy Top Building at Loughborough University.

Kinetic data were collected with a Kistler force plate in conjunction with a Coda Mpx30 motion analysis system, as outlined in section 3.4.1. The load was carried using a standard issue UK '90 Pattern Short Back Bergen and PLCE waist webbing, which when worn together form a load carriage system (LCS). The rifle carried was a weighted replica SA80 assault rifle, weighing 4.4 kg. The rifle was weighted to represent the load distribution of the actual SA80 carried by British troops (see section 3.2.3). To simulate the fixed arm position induced by rifle carriage a lightweight rifle mock-up with approximate dimensions of the SA80 was used. The weight of the rifle was reproduced by participants wearing a diving belt with a load of 4.4 kg attached. The mass was placed close to the body's neutral centre of mass as it would be if the actual rifle was being carried but allowing the arms to move freely. Figure 5.1 shows how these rifle conditions were replicated. Participants wore standard issue military leather boots throughout.

5.3.2 Protocol

Participants completed all 7 conditions (table 5.1, figure 5.1), with 10 successful trials in each condition. Kinetic data were sampled at 400 Hz and the target walking speed throughout was 1.5 $m.s^{-1}$ ($\pm$ 5%). A trial was deemed successful if the speed was attained, the foot struck cleanly on the force plate and if a natural gait pattern was maintained. To ensure participants had familiarised themselves with the load and walking speed an unlimited number of practice walks were allowed.

Table 5.1: Description of the conditions used during the study.

Condition	Description
Boot	Wearing non-restrictive clothing and military boots
Fixed Arms	As boot but carrying a lightweight SA80 rifle simulator
Fixed Mass	As boot with the addition of a 4.4 kg diving belt
Rifle	As boot with the addition of the weighted SA80 rifle
Webbing	As rifle with the addition of webbing weighing 8 kg
LCS	As Webbing with addition of Bergen weighing 16 kg
LCS No Rifle	As LCS but carrying no rifle

Figure 5.1: Illustration of the rifle or load carriage conditions used in this study. Not included in figure is boot condition where no rifle or load were carried.

5.3.3 Parameters Measured and Data Analysis

GRF parameters were collected, normalised and means calculated for every condition. However, only the eight major parameters were considered for analysis. Again underlying reasons for this are detailed in section 3.6.1. The participants' kinetic data were normalised and expressed as Newton's per unit body mass

($N.BM^{-1}$), allowing direct comparison between participants. Data from the boot, fixed arms and LCS no rifle conditions were normalised to bodyweight (including clothes and boots), the other conditions to system weight (this is the weight of the rifle added to that of the participant). All data are expressed as $N.BM^{-1}$ but as explained above this may either be the weight of the participant alone, or with the rifle.

5.3.4 Statistical Analysis

The main aim of the study was to evaluate the effect of rifle carriage on GRFs and discover the mechanisms behind the potential changes. For this the boot, fixed arms, fixed mass and rifle conditions were subject to combined analysis (table 5.1). Statistical significance was determined for the eight selected GRF parameters by the use of one-way (repeated measures) ANOVAs, this analysed overall differences as a result of the rifle carriage conditions. To assess potential differences between the four rifle carriage conditions (table 5.1), Bonferroni corrected pairwise comparisons were also conducted.

To re-assess the effect of load carriage on GRF parameters the rifle, webbing and LCS conditions were used (table 5.1). One-way (repeated measures) ANOVAs with Bonferroni correction were selected to determine levels of significance as a result of load carriage. To determine potential differences when carrying a load with or without a rifle (between the LCS and LCS no rifle condition), paired Student t-tests were performed. Again only the eight major GRF parameters were analysed.

5.4 Results

5.4.1 Rifle Carriage

The rifle carriage conditions implemented during this study elicited numerous changes to GRF parameters measured, many of which were statistically significant (table 5.2). Table 5.3 shows the conditions which differed significantly during pairwise comparisons, and indicates which of the conditions exhibited the greater value of force. Below is a summary of the main findings with respect to the difference between the rifle carriage conditions:

Impact Peak – Significant increase from the boot condition to both the rifle and fixed arms condition. This suggests the principal mechanism behind the increase in impact peak between the boot and rifle condition is the restriction of natural arm movements (figure 5.2(b)).

Force Minimum – Restricted arm movements (rifle and fixed arms condition) significantly decreased the force minimum compared to the boot condition. There was no difference between the fixed mass and boot condition (figure 5.2(c)).

Thrust Maximum – Carrying a load of 4.4 kg (rifle or fixed mass condition) significantly decreased the thrust maximum compared to the fixed arms condition. No difference between the fixed arms and boot condition (figure 5.2(d)).

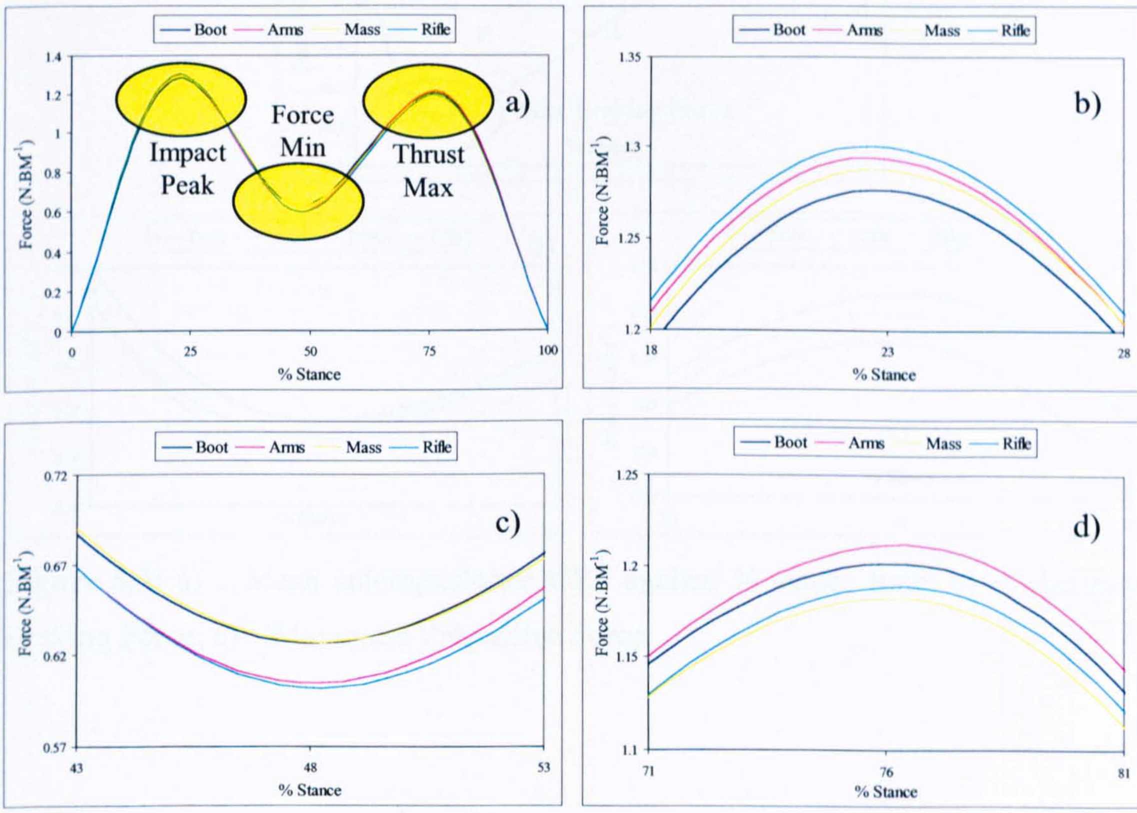


Figure 5.2: a) – Mean vertical GRF against % stance time; b) – Impact Peak; c) – Force Minimum; d) – Thrust Maximum.

Maximum Braking Force – A significant increase in maximum braking force was observed between the rifle and fixed mass condition. No other differences were observed (figure 5.3(b)).

Maximum Propulsive Force – Restricted arm movements (rifle and fixed arms) significantly increased maximum propulsive force compared to the boot condition (figure 5.3(c)).

Mediolateral Impulse – Rifle carriage significantly increases mediolateral impulse compared to the boot and fixed arms condition. No difference was observed between the fixed arms and boot condition.

Other Parameters – No other significant differences were observed between the stance time and vertical impulse between any of the rifle carriage conditions.

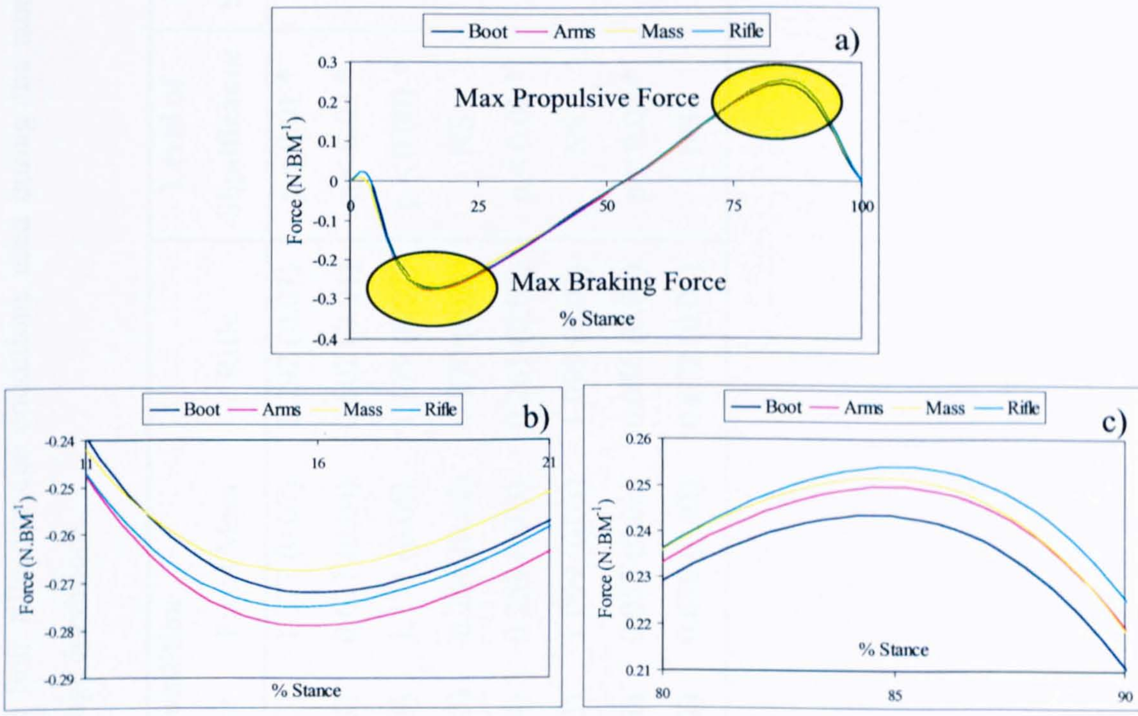


Figure 5.3: a) – Mean anteroposterior GRF against % stance time; b) – Maximum Braking Force; c) – Maximum Propulsive Force.

Table 5.2: Changes to selected mean GRF parameters for the four rifle carriage conditions used during the study, standard deviation in parentheses. * indicates significant main effect with the rifle carriage conditions.

GRF Parameter	Condition				Level of Significance	Bonferroni Significance
	Boot	Fixed Arms	Fixed Mass	Rifle		
Impact Peak	1.256 (0.07)	1.284 (0.07)	1.277 (0.07)	1.292 (0.07)	$p < 0.01$ *	Yes
Force Minimum	0.626 (0.04)	0.604 (0.04)	0.627 (0.04)	0.602 (0.04)	$p < 0.01$ *	Yes
Thrust Maximum	1.191 (0.08)	1.202 (0.07)	1.171 (0.06)	1.179 (0.07)	$p < 0.001$ *	Yes
Max Braking Force	-0.267 (0.03)	-0.273 (0.03)	-0.266 (0.02)	-0.270 (0.02)	NS	No
Max Propulsive Force	0.249 (0.03)	0.259 (0.04)	0.259 (0.03)	0.261 (0.03)	$p < 0.01$ *	Yes
Vertical Impulse	1.110 (0.04)	1.108 (0.03)	1.099 (0.03)	1.099 (0.02)	NS	No
Mediolateral Impulse	0.050 (0.01)	0.052 (0.01)	0.053 (0.01)	0.056 (0.01)	$p < 0.01$ *	Yes
Stance Time	0.677 (0.02)	0.675 (0.02)	0.670 (0.02)	0.672 (0.02)	NS	No

Table 5.3: Pairwise comparisons between rifle carriage conditions tested. 'Yes' indicates a significant difference between the two conditions, indicated after significance is the condition which exhibited the greater force.

	Pairwise Significance Between Conditions						
GRF Parameter	**Boot-Arms**	**Boot-Mass**	**Boot-Rifle**	**Arms-Mass**	**Arms-Rifle**	**Mass-Rifle**	**Overall**
Impact Peak	Yes - Arms	No	Yes – Rifle	No	No	No	$p < 0.01$ *
Thrust Maximum	No	No	No	Yes - Arms	Yes - Arms	No	$p < 0.01$ *
Force Minimum	Yes - Boot	No	Yes – Boot	Yes - Mass	No	Yes - Mass	$p < 0.001$ *
Max Braking Force	No	No	No	No	No	Yes - Rifle	NS
Max Propulsive Force	Yes - Arms	No	Yes – Rifle	No	No	No	$p < 0.01$ *
Vertical Impulse	No	No	No	No	No	No	NS
Mediolateral Impulse	No	No	Yes – Rifle	No	Yes - Rifle	No	$p < 0.01$ *
Stance Time	No	No	No	No	No	No	NS

5.4.2 Effect of Load

Results show that carrying a rifle whilst carrying a load of 24 kg decreased the force minimum and thrust maximum compared to load carriage with no rifle (table 5.4). However, no differences were observed to any other measured GRF parameter.

Table 5.4: Mean GRF parameters for rifle carriage with or without load, standard deviation in parentheses. * indicates significance with Bonferroni correction.

GRF Parameter	Condition		Level of
	LCS	LCS No Rifle	Significance
Impact Peak	1.597 (0.13)	1.603 (0.10)	NS
Force Minimum	0.749 (0.06)	0.772 (0.05)	p < 0.01 *
Thrust Maximum	1.516 (0.11)	1.549 (0.11)	P < 0.001 *
Max Braking Force	-0.339 (0.04)	-0.342 (0.04)	NS
Max Propulsive Force	0.325 (0.04)	0.328 (0.03)	NS
Vertical Impulse	1.426 (0.06)	1.438 (0.07)	NS
Mediolateral Impulse	0.061 (0.01)	0.065 (0.01)	NS
Stance Time	0.692 (0.03)	0.691 (0.02)	NS

As well as examining the effects of rifle carriage on gait, this study also re-examined the effects of load carriage. The load carried increased from 0 kg in the rifle condition to 8 kg with the webbing and finally 24 kg in the LCS condition. As can be seen in table 5.5 all the major GRF parameters measured increased significantly as load was added. As well as the overall effect of load, pairwise comparisons determined that all parameters, with the exception of mediolateral impulse, increased significantly ($p<0.05$) between each condition.

Table 5.5: Selected mean GRF parameters for the effect of load, standard deviation in parentheses. * indicates significance.

GRF Parameter	**Condition**			**Level of**
	Rifle	Webbing	LCS	**Significance**
Impact Peak	1.292 (0.07)	1.391 (0.08)	1.597 (0.13)	p < 0.001 *
Force Minimum	0.602 (0.04)	0.661 (0.06)	0.749 (0.06)	p < 0.001 *
Thrust Maximum	1.179 (0.07)	1.306 (0.08)	1.516 (0.11)	p < 0.001 *
Max Braking Force	-0.270 (0.02)	-0.299 (0.03)	-0.339 (0.04)	p < 0.001 *
Max Propulsive Force	0.261 (0.03)	0.284 (0.02)	0.325 (0.04)	p < 0.001 *
Vertical Impulse	1.099 (0.02)	1.219 (0.05)	1.426 (0.06)	p < 0.001 *
Mediolateral Impulse	0.056 (0.01)	0.058 (0.01)	0.061 (0.01)	p < 0.01 *
Stance Time	0.672 (0.02)	0.682 (0.02)	0.692 (0.03)	p < 0.001 *

5.5 Discussion

5.5.1 Rifle Carriage

The effects that rifle carriage has on the kinetics of human gait have not been researched before, to the authors' knowledge. For this reason the discussion section will draw conclusions from related restricted arm movement or load carriage literature. The results from the study cannot be corroborated with other published work, other than the findings presented in Chapter 4 of this thesis.

The most interesting results from the study relate to the increase in impact peak, or force produced at heel strike, when carrying the rifle. It is important to note that the increase in GRF observed is not a direct result of the increased mass of the system due to rifle carriage. All data were normalised to account for any changes in mass. A significant increase was also observed between the boot and fixed arms condition. This suggests that the restriction of natural arm swing patterns is the principal mechanism behind the observed increase in the impact peak GRF parameter. Another interesting and surprising finding was the increase in mediolateral impulse observed with rifle carriage. This was again attributed to the restriction of natural arm swing. Both of these findings were reported in Chapter 4; however, mechanisms for the increases can now be suggested. The rest of the discussion will focus in more detail on these and other findings from the current study.

Impact Peak

Focusing firstly on the effects of rifle carriage on the impact peak or force produced during heel strike phase of gait (figure 5.2, panel B). Rifle carriage resulted in a 3% increase in the impact peak compared to the boot condition (used as a control or baseline) (figure 5.5). Two thirds of the increase from the boot to rifle condition was due to the restricted arm movements induced by rifle carriage (figure 5.2, panel B). The reason for this increase is most likely due to the greater downward acceleration of the CoM just before heel strike. The remaining third was as a result of the mass of the rifle.

Natural arm movements during walking have been shown to modulate the vertical excursions of the body's CoM (Elftman, 1939; Murray et al, 1967; Hinrichs and Cavanagh, 1981). Therefore, it is assumed that restricted arm movements will impede this and result in a greater vertical range of motion travelled by the CoM. During normal walking the body's CoM displays a sinusoidal oscillation that peaks and troughs twice during a single stride (figure 5.4). The two peaks present on the CoM position curve occur approximately at the same time as the force minimum GRF parameter in the vertical axis, or when the foot of the swinging limb is adjacent to the stance foot. The troughs generally occur just after heel strike and during the period of double support. The maximum velocity of the CoM (in either the up or downward direction) occurs just after the maximum acceleration of the CoM. The peak acceleration of the CoM in the downward vertical direction occurs regularly at the trough of the CoM position curve. This is represented in the positive axis in figure 5.4, as the Coda equipment used in this study designates acceleration with gravity (downward) as being positive. The respective peak of the upward acceleration of the CoM occurs at the peak of the CoM position curve. The implication of this is that changes in the position of the CoM, e.g. an increase in the range of motion, will have knock on effects to the acceleration of the body's CoM. With respect to the impact peak, a greater range of motion of the CoM will lead to increased acceleration due to gravity of the CoM towards the ground at heel strike. This in turn will produce a greater impact peak reaction force, in accordance with Newton's 2nd Law.

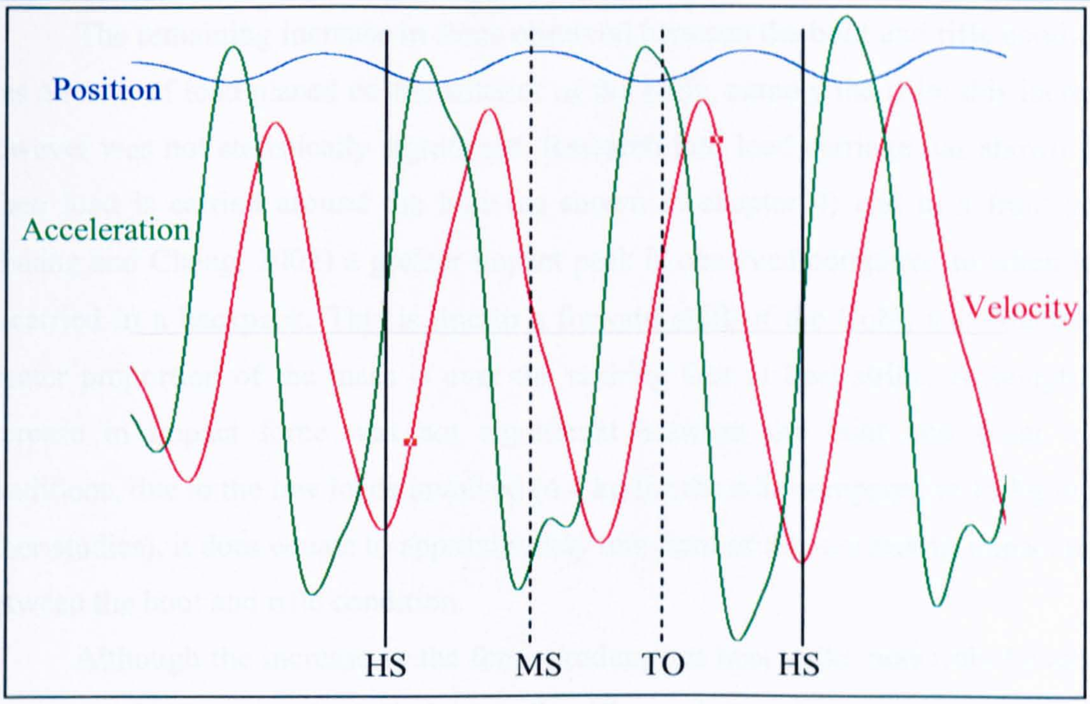


Figure 5.4: Example of the CoM position, velocity and acceleration with respect to their occurrence in the gait cycle (HS, MS TO and refer to heel strike, mid-stance and toe-off respectively).

As well as increasing the range of motion of the CoM, restricted arm movements may have other effects that result in the observed changes to the GRF parameters. These may include changes to the stride parameters of gait. Harman et al (2001) showed that carrying a LCS which restricted the rearward arm swing led to reductions in stride length, independent to the load carried. However, a reduction in stride length is generally not attributed as causing significant changes in GRF parameters. The more common scenario observed is an increase in stride length being linked to increases in the anteroposterior axis of GRF (Martin and Marsh, 1992; Harman et al, 2001) and stance time (Martin and Marsh, 1992) during walking. Challis (2001) showed that during running, a stride length which was longer than the preferred stride length led to increases in impact peak and a decrease in percentage time to reach this peak. No significant differences were observed when the stride length was shorter than the preferred length with either the Martin and Marsh (1992) or the Challis (2001) studies. This adds further weight to the notion that the changes seen with rifle carriage in this study are as a result of changes to the CoM, and not the restriction of arm movements causing changes to stride parameters.

The remaining increase in force observed between the boot and rifle condition was a result of load placed on the anterior of the body, namely the rifle; this increase however was not statistically significant. Research into load carriage has shown that when load is carried around the hips (as shown in chapter 4) and in a front pack (Hsiang and Chang, 2002) a greater impact peak is observed compared to when load is carried in a backpack. This is due to a forward shift of the CoM, subsequently a greater proportion of the mass is over the striking foot at heel strike. Although the increase in impact force was not significant between the boot and fixed mass conditions, due to the low loads involved (4.4 kg for the rifle compared to 16 kg in the other studies), it does equate to approximately one third of the increase in impact peak between the boot and rifle condition.

Although the increase in the force produced at heel strike may only be small, at around a 3% increase from the boot to the rifle condition, this occurs at every stride taken and is in addition to the load that may be carried. For the average participant who took part in this study (mass 83.3 kg), carrying the rifle increased the force needed to be absorbed by the supporting leg by 29.42 N per stride. Military recruits can cover up to 11 km per day, which equates to around 9,000 impacts (Jones et al, 2001). As mentioned previously this small but potentially significant increase in force is in addition to other factors such as load carriage or walking / running speed. It is unknown whether an increase in the force needed to be dissipated by the body of 29.42 N for up to 9,000 impacts is of clinical significance, and if so to what extent this may alter the number of overuse injuries sustained by members of the military.

The premise for this study originated from the initial GRF and load carriage research conducted and described in chapter 4. This previous work found an increase in the impact peak whilst carrying a replica un-weighted SA80 rifle. Data from the current study shows the mean impact peak during rifle carriage to be slightly higher but comparable to this previous study (1.292 verses 1.226 $N.BM^{-1}$, respectively). This difference may be due to the increased weight of the rifle used in the current study or simply down to participant variation.

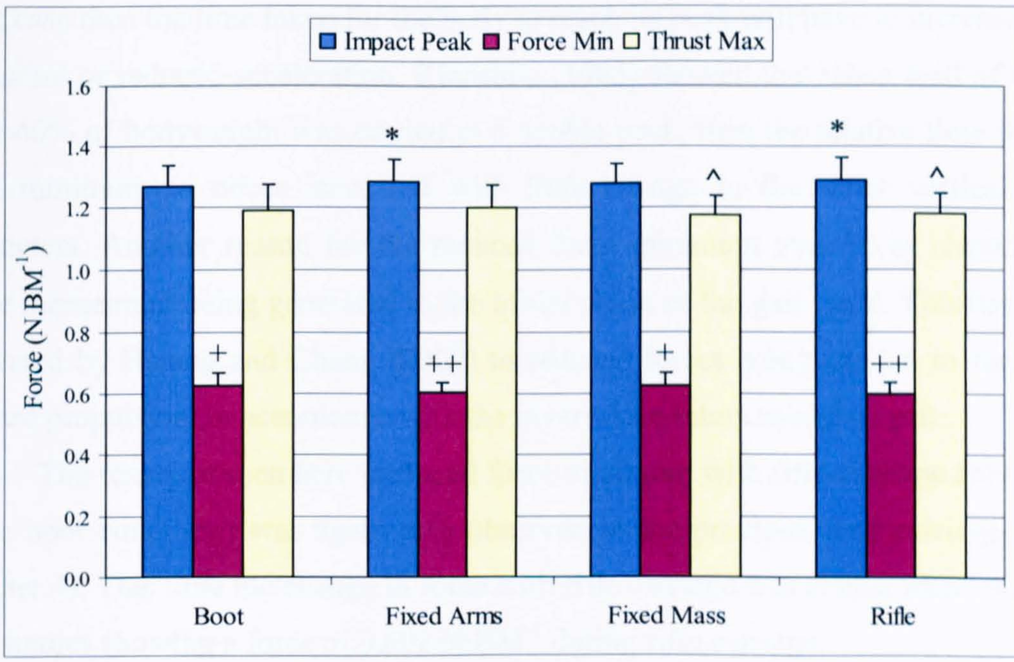


Figure 5.5: Mean vertical GRF parameters for rifle carriage conditions, (error bars represent standard deviation).

* indicates significant difference with the impact peak from the boot condition.

^ significant difference from fixed arms condition with the thrust maximum.

+ significant differences from fixed arms and rifle condition, ++ from boot and fixed mass condition with the force minimum.

Force Minimum

An interesting occurrence was seen regarding the force minimum. Restricted arm movements as caused by the rifle and fixed arms condition produced a lower force minimum compared to free arm movements in the boot and fixed mass condition (figure 5.2, panel C). This difference was approximately twice that of the impact peak at around 4%. There was no significant difference between the rifle and fixed arms or between the boot and fixed mass condition (figure 5.5). Even though the difference with the force minimum produced some of the clearest and most significant results, mechanisms behind the observed differences are uncertain. During mid-stance (at which the force minimum occurs) the body's CoM reaches its vertical peak. The assumption is that restricted arm movements will cause the CoM to attain a higher peak compared to free arm movements. The force produced during walking is a product of the mass and acceleration of the body. For the vertically higher CoM to be reached the acceleration of the body does not necessarily have to be increased. If this is the case then the time taken for the body to reach its peak will have to increase with a constant or reduced acceleration. Kinoshita (1985) showed that when load of either 20 or 40% of bodyweight was carried in a double-pack, then the relative time for the force minimum to occur increased with little change in the other vertical time parameters. Another reason for the reduced force minimum may be in response to active momentum being generated in the initial phase of the gait cycle. This has been suggested by Hsiang and Chang (2002) to reduced forces being needed to facilitate forward propulsion, in accordance with the inverse pendulum model of gait.

The response seen here (reduced force minimum with rifle carriage compared to the boot condition) was again also observed in the previous load carriage study (chapter 4). This time the change in force with rifle carriage was almost identical with both studies showing a force of 0.602 $N.BM^{-1}$ during rifle carriage.

Thrust Maximum

The carrying of load in front of the body (rifle and fixed mass condition) produced a trend for a decreased thrust maximum, or force produced at toe-off (figure 5.2, panel D). Statistically significant differences were observed with the fixed arms conditions producing a higher force compared to the fixed mass and rifle conditions (figure 5.5). This observation is more difficult to explain as a decreased thrust maximum may be as a result of active momentum being produced earlier in the gait. Other potential mechanisms are reduced extension of the knee during push-off or the potential of load carried to alter the forward lean of the participant. Neither of these explanations is sufficient to explain the decrease in thrust maximum observed here. Further research is needed to corroborate and explain this finding.

Maximum Braking and Propulsive Force

Restricted arm movements, as caused by the rifle or fixed arms condition, resulted in an increase in both the maximum braking and propulsive force produced during walking (figure 5.3). A statistically significantly greater maximum braking force was observed between the fixed mass and rifle condition (figure 5.6). This was the only difference between the conditions adopted, this is despite the fixed arms condition producing a greater negative mean force. Therefore it can be suggested that restricted arm movements (fixed arms or rifle condition) produce a greater maximum braking force compared to the boot and fixed mass condition. Although no main statistical effect was observed. A potential reason for this again may be due to the increased vertical acceleration of the body's CoM caused by restricted arm movements. The CoM is slowed during mid-stance (figure 5.4) and then propelled forward again during toe-off. The greater the acceleration of the body at heel strike may lead to greater braking forces being needed to slow the body, hence the increased braking force with restricted arm movements.

Changes to the maximum propulsive force were clearer with respect to the effect of rifle carriage. Observable differences (figure 5.6) were only found with the boot (or control condition) displaying lower forces compared to the fixed arms and rifle condition (in other words restriction of natural arm swing). Some research has suggested that arm swing does not contribute to the drive (or the forward propulsion of the body) during walking (Murray et al, 1967) or running (Hinrichs, 1990). Reasons given for this are that the forward drive produced by the forward swinging arm is negated by that produced by the opposite arm swinging backwards. This idea of the arms not contributing to the propulsion of the body is one that this thesis challenges; reasons for this are: Gutnik et al (2005) state that 'The energy of flexion in each cycle was several times greater than the energy of extension'. The muscles involved in flexion of the upper limb are bigger and more powerful than those of extension. The drive produced by the arms is an essential part of successful performance in running and jumping events. Arm swing during vertical jumps increases the upward lift of the body (Feltner et al, 2004; Lees et al, 2004). Finally, if arm swing does not contribute to the forward propulsion of the body, this current study would not have shown significant differences as a result of restricted arm swing due to rifle carriage. Results from this study and in Chapter 4 suggest that during rifle carriage the restricted arm movements cause an increase in the maximum propulsive force produced.

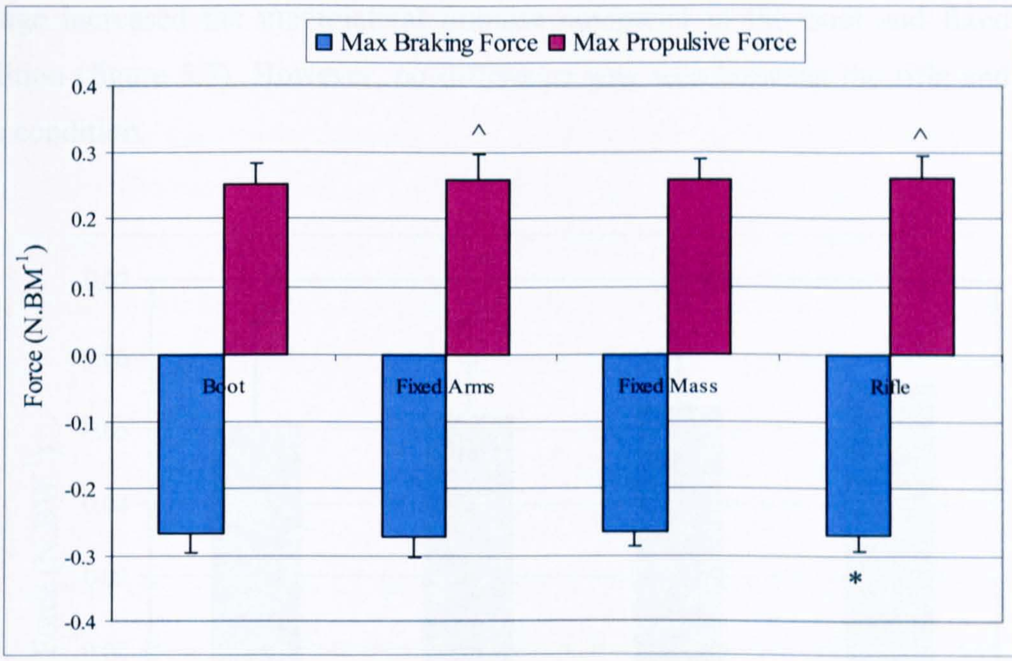


Figure 5.6: Mean anteroposterior GRF parameters for rifle carriage conditions, (error bars represent standard deviation).
* indicates significant difference between fixed mass condition with the braking force.
^ indicates significant difference from boot condition with the propulsive force.

The changes observed to the maximum propulsive force with rifle carriage seen during this study were again seen with the load carriage study in chapter 4. Both studies displayed increased propulsive forces with rifle carriage compared to the boot condition. The values recorded during both studies differed to a small extent, with force in the boot condition being 0.215 in the load carriage study and 0.249 with this study and for the rifle condition 0.222 and 0.261 respectively. Although the absolute values may be different the trend for a 4 – 5% increase in maximum propulsive was the same for both studies. Differences again may be due to the weight of the rifle carried or participant variation.

Mediolateral Forces

Changes to the mediolateral forces during gait are generally regarded as the least important of the three axes, with much research into load carriage regarding them of limited consequence (Kinoshita, 1985; Lloyd and Cooke, 2000; Harman et al, 2000). This research however has highlighted observable differences that occur in the mediolateral axes during rifle carriage, or conditions that replicate rifle carriage. Rifle carriage increased the mediolateral impulse compared to the boot and fixed arms condition (figure 5.7). However, no difference was seen between the rifle and fixed mass condition.

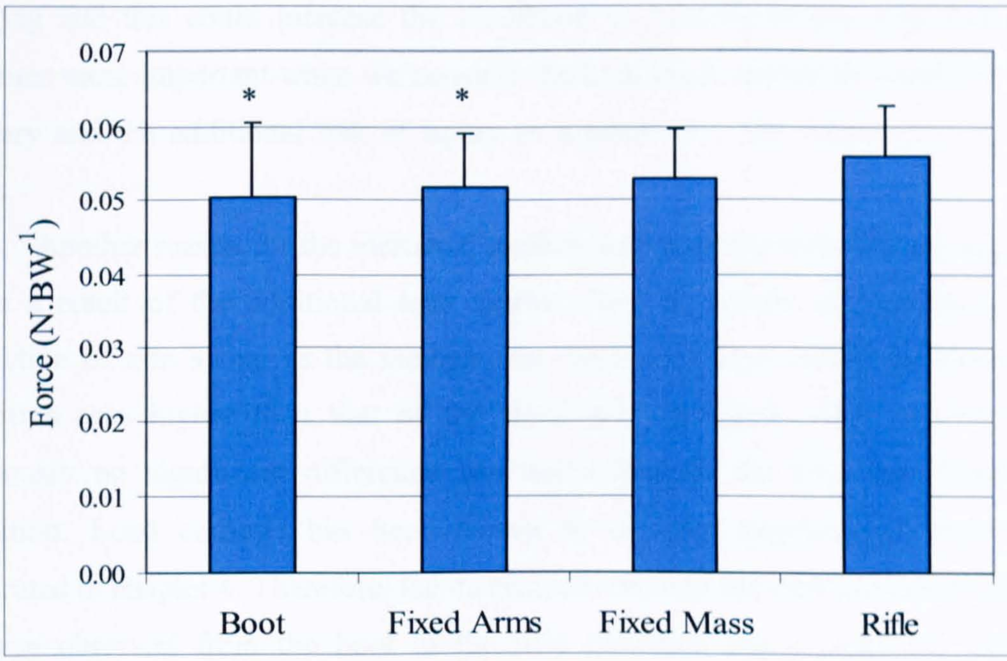


Figure 5.7: Mean mediolateral impulse for rifle carriage conditions, (error bars represent standard deviation).
* indicates significant difference from the rifle condition.

The differences observed with the mediolateral impulse may be as a result of an increased horizontal excursion of the body's CoM, leading to a decrease in stability or increased need for greater postural control. As mentioned previously, natural arm swing patterns serve to counterbalance horizontal rotation of the trunk and also help to modulate the CoM in both the vertical and horizontal direction (Elftman, 1939; Murray et al, 1967; Hinrichs and Cavanagh, 1981). Therefore it's assumed that restricted arm movements will impede this stabilising factor. The greater range of motion of the body's CoM in the horizontal plane may lead to increased mediolateral forces. Greater mediolateral force may indicate either a decrease in stability of the participant or, in order to maintain stability, greater postural control will be needed. Increasing the work needed to be done by the muscles of the trunk may increase the stresses or strain placed on this musculature and also increase energy cost. In clinical terms an increased mediolateral minimum force (or force in the lateral direction, away from the mid-line of the body) at heel strike may be related to an increased inversion of the foot during initial impact. If this force is excessive enough or repeated many times this may lead to problems or injury to the ankle and knee joints (Sacco et al, 2006). Increased mediolateral impulse may also indicate a decrease in stability while walking and this could increase the likelihood or severity of potential falls. This becomes more important when we consider the high loads carried by members of the military and the additional risk of injury as a result of a fall whilst carrying these loads.

Another reason for the increased mediolateral impulse with rifle carriage may be as a result of the additional load carried. This is equally as important as the restriction of arm swing as the mediolateral force generated during the fixed mass condition was higher than that of the fixed arm condition. Also, as mentioned previously no significant difference was seen between the rifle and fixed mass condition. Load carriage has been shown to increase mediolateral impulse, as illustrated in chapter 4. Therefore, the mechanisms behind the increase in mediolateral impulse observed from the boot to the rifle condition are a combined effect of restricted arm swing and the additional load.

Other Parameters

No significant relationships were observed for other GRF parameters that were measured, namely vertical impulse and stance time. The lack of change in the vertical impulse is not surprising given the significant increase in impact peak and decrease in force minimum. These changes will cancel each other out somewhat. Also, with no changes to stance time it can be suggested that rifle carriage does not affect single support time parameters. This is supported by Eke-Okoro et al (1997) who also found that restricted arm swing led to no alterations in stance time.

5.5.2 Load Carriage With or Without a Rifle

The effect of carrying 24 kg in a military LCS either with or without the addition of rifle carriage was also analysed. As shown in table 5.4 rifle carriage with load (LCS condition) resulted in a significant ($p<0.05$) decrease in the force minimum and thrust maximum compared to load carriage with no rifle (LCS No Rifle). The decrease in force minimum with rifle carriage whilst carrying loads was expected as results from the rifle carriage section of the study suggest that the restriction of natural arm swing patterns leads to a significant reduction in the force produced during mid-stance. Also expected was the lesser force produced at toe-off, or the thrust maximum, as when load was carried in front of the body a decrease in thrust maximum was seen. None of the other GRF parameters measured showed any differences with rifle carriage. This factor may a result of that during load carriage the more predominant increase observed as a result of the additional 24 kg of carried load over-rode the more subtle changes associated with rifle carriage. Despite this, important and relevant changes to gait pattern were still observed with rifle and load carriage combined.

5.5.3 The Effect of Load

This element of the current study was designed to corroborate and extend conclusions from the heavy load carriage study (chapter 4). Firstly, that vertical and anteroposterior GRFs increase proportionally when load is added to the body in military LCS. Secondly, that only 3 conditions are required to accurately predict the linear increase in force that will occur. Finally, that the observed increases to stance time and mediolateral impulse with additional load were not coincidental.

Figure 5.8 shows the expected increase in vertical and anteroposterior force as load is added to the body, with parameters in table 5.5 showing highly significant outcomes. In addition, increases with load were also again observed with the stance time and mediolateral impulse, thus providing further clarification to the observations in the load carriage study about increasing load and subsequent decreasing stability. Again all GRF parameters, with the exception of mediolateral impulse, showed significant increases between conditions with pairwise comparisons. Although not identical the force values generated during this study are comparable to those of the previous load carriage study.

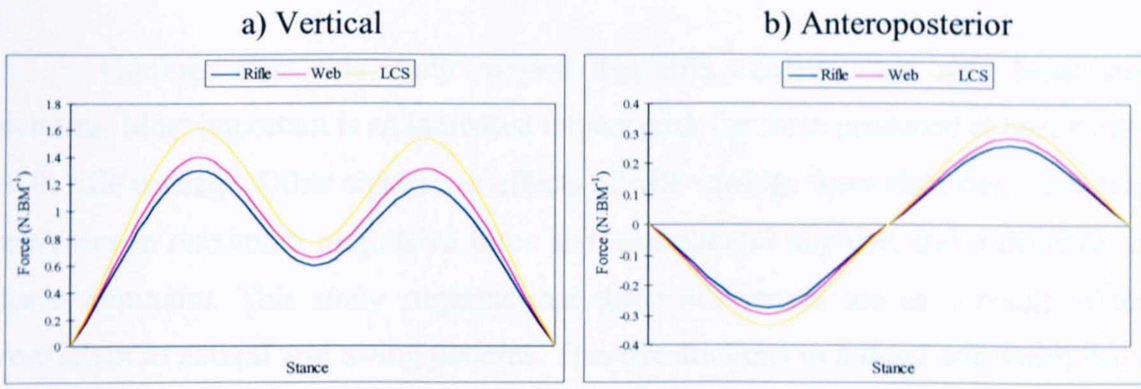


Figure 5.8: A graphical representation of mean vertical (a) and anteroposterior (b) GRFs produced when carrying 0, 8 and 24 kg (rifle, web and LCS, respectively).

Finally, figure 5.9 shows a linear increase in the force produced with load. This confirms that both vertical and anteroposterior GRF parameters increase proportionally when load is added to the body, as no tailing off or plateau is observed. See chapter 4 for further discussion on the impact and implications of load carriage.

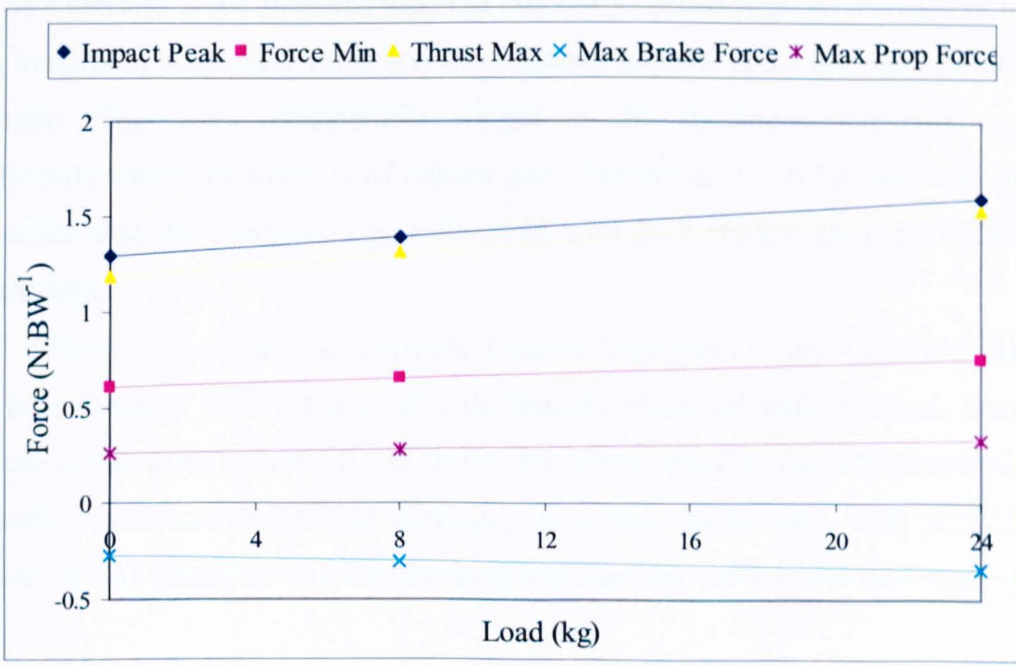


Figure 5.9: Linear increases in the mean vertical and anteroposterior GRF parameters with increase in load.

5.6 Conclusions

Findings from this study suggest that rifle carriage does alter basal gait patterns. Most important is an increased impact peak (or force produced at heel strike) with rifle carriage. Other significant effects of rifle carriage were also seen, including increases in maximum propulsive force and mediolateral impulse, and a decrease in force minimum. This study suggests that these differences are as a result of the restriction in natural arm swing patterns. These restrictions in natural arm swing have been shown previously to increase both the horizontal and vertical range of motion of the body's centre of mass. This in turn is suggested to be the principal mechanism behind the changes to kinetic parameters observed in this study. This leads to the accepting of hypotheses 1 and 2. Rifle carriage is essential within the military but the subsequent possible effect on the potential development of injuries remains unknown. This study has highlighted and scientifically showed that rifle carriage alters basal gait patterns, a previously unreported aspect of military load carriage.

Another important conclusion is that all of the changes observed in chapter 4 with rifle carriage were observed again in this study. These were an increase in impact peak, maximum propulsive force and mediolateral impulse and a decrease in the force minimum. This adds considerable weight to the statement that rifle carriage significantly alters the kinetics of human gait. Therefore, it can be said with greater confidence that the changes to gait observed with both studies are actual effects of rifle carriage.

Other conclusions that partially support hypothesis 3 are that rifle carriage with load displays some of the same differences observed with no load, namely a decrease in the force minimum and thrust maximum. Finally, that all measured GRF parameters increased with load carriage, including stance time and mediolateral impulse, as was observed with the previous load carriage study presented in chapter 4.

Chapter Six – Effect of Load Distribution in Military LCS on GRF Parameters

6.1 Introduction

The literature review presented in Chapter 2 identified that changing the distribution of load carried on the body can alter the biomechanical parameters of gait. Despite this finding relatively few studies have been conducted, and universally agreed changes in gait have not been established. This was reaffirmed by the differences found in Chapter 4, as observed when 16 kg were carried in the backpack compared to the webbing. This current chapter develops on this preliminary work further, both in terms of the methodologically approach adopted and the detail of the discussion in regards to the relevant literature. The aim of the study was to investigate the effect that altering the load distribution between 3 military load carriage systems (LCS) has on ground reaction force (GRF) parameters. Loads ranging between 8 and 32 kg were carried in 3 different military LCS. Each of these systems resulted in the body's centre of mass (CoM) being significantly altered. A lab based study was conducted using 12 load and LCS combinations to test the following hypotheses:

H_1: Altering load distribution will change the GRF parameters during walking.
H_0: Altering load distribution will not change the GRF parameters during walking.
H_2: Evenly distributing load on the body is biomechanically more favourable.
H_0: Evenly distributing load on the body is biomechanically more unfavourable.

6.2 Background

The effect that military load carriage has on GRF parameters has been examined previously in the literature and in Chapter 4 of this thesis. However, less attention has been paid to when load is distributed more evenly on the body, particularly with respects to the biomechanical changes of gait. It has long been suggested that the most efficient way to load the body is by keeping it as close as possible to the body's CoM, while also utilising the larger muscle groups. This is true for both physiological and biomechanical parameters. However, due to various ergonomic reasons the backpack is the only really viable option for members of the military to carry their own equipment. Research has shown that placing load closer to the body's CoM results in a reduction in energy cost, and a more upright walking posture being adopted (or reduced forward lean). In terms of the kinetic effects a reduced maximum braking force and stance time, while increasing force minimum are frequent outcomes as a result of distributing load around the trunk. To the author's knowledge only five published studies have investigated the effect of load distribution on GRF parameters (Kinoshita, 1985; Lloyd and Cooke, 2000, Harman et al, 2001; Hsiang and Chang, 2002, Koulmann, 2006). These available studies have generally been restricted to between 4 and 6 load and carrying system combinations.

6.3 Methodology

6.3.1 Participants and Equipment

Twelve male participants volunteered for the study (mass 81.3 kg ± 9.9 S.D., height 184.4 cm ± 6.2, age 29.2 years ± 9.0). Ethical approval was gained from the Loughborough University Ethical Advisory Committee under the generic load carriage protocol (G03/P18). All participants volunteering for the study had previous experience carrying military style backpacks, all were right foot dominant and rear-foot strikers. A verbal and written explanation of the study was given, after which a health screen questionnaire was completed. Finally signed, informed consent was obtained from all participants before commencing the trial. Testing took place between 19th March and 24th April 2006 and was conducted in the Ergonomics Laboratory in the Wavy Top Building at Loughborough University.

Kinetic data were collected using a Kistler force plate in conjunction with a Coda Mpx30 motion analysis system, as outlined in section 3.4.1. To assess the differences caused by altering the load distribution three LCS were adopted, and 4 different loads were carried 8, 16, 24 and 32 kg (see section 3.2 for more details on the LCS used, important features and how load was distributed). Participants also wore standard issue military leather boots and woollen socks throughout the testing session. The three LCS used for this study were:

1. Backpack LCS – Load solely carried in the '90 Pattern short back Bergen.
2. Standard LCS – This utilised the standard issue UK '90 Pattern Short back Bergen and PLCE waist webbing.
3. AirMesh LCS – This consisted of AirMesh Prototype III Bergen and PLCE vest webbing.

6.3.2 Protocol

Participants completed 13 conditions (table 6.1), with 10 successful trials required for each condition. Kinetic data were sampled at 400 Hz and walking speed for all conditions was 1.5 $m.s^{-1}$ (± 5%). A trial was deemed successful if the foot struck cleanly on the force plate, a natural gait pattern was maintained and the walking speed was within the desired range. To ensure the participants had familiarised themselves with the protocol an unlimited number of practice trials were allowed. In all loading conditions a weighted replica SA80 assault rifle was carried (see section 3.2.2 for details on the rifle carried).

Table 6.1: Description of conditions during the study.

Condition	Description
Rifle	Carrying weighted replica SA80 rifle, used as a control
BP 8kg	Carrying 8 kg in '90 Pattern Bergen
BP 16kg	Carrying 16 kg in '90 Pattern Bergen
BP 24 kg	Carrying 24 kg in '90 Pattern Bergen
BP 32 kg	Carrying 32 kg in '90 Pattern Bergen
STD 8kg	Carrying 8 kg in waist webbing
STD 16kg	Carrying 16 kg in waist webbing
STD 24kg	Carrying 8kg in waist webbing and 16kg in '90 Pattern Bergen
STD 32kg	Carrying 16kg in waist webbing and 16kg in '90 Pattern Bergen
AM 8kg	Carrying 8 kg in vest webbing
AM 16kg	Carrying 16 kg in vest webbing
AM 24kg	Carrying 8kg in vest webbing and 16kg in AirMesh Bergen
AM 32kg	Carrying 16kg in vest webbing and 16kg in AirMesh Bergen

The use of the conditions outlined in table 6.1 had the effect of progressively distributing load more evenly around the trunk. Although the body's CoM was not measured it is readily apparent that the 3 LCS adopted with this study significantly altered its position. The backpack LCS displaces the CoM furthest away from its neutral position, with all the load carried on the posterior of the body. The standard LCS then starts to modify this with a proportion of load placed around the hips. Finally, the AirMesh LCS distributes load on both the anterior and posterior of the body. This system results in the least displacement of the body's CoM from its neutral position. Figure 6.1 shows the LCS used when loads of 8 and 16 kg were carried. In these conditions load is carried in only one piece of equipment, either the webbing or Bergen. Figure 6.2 shows the 3 LCS when loads of 24 and 32 kg are carried. As can be seen in the standard and AirMesh LCS both the webbing and Bergen is worn; however, with the backpack LCS load is solely carried in the Bergen.

Figure 6.1: Backpack, Standard and AirMesh LCS (left to right respectively) when 8 or 16 kg were carried.

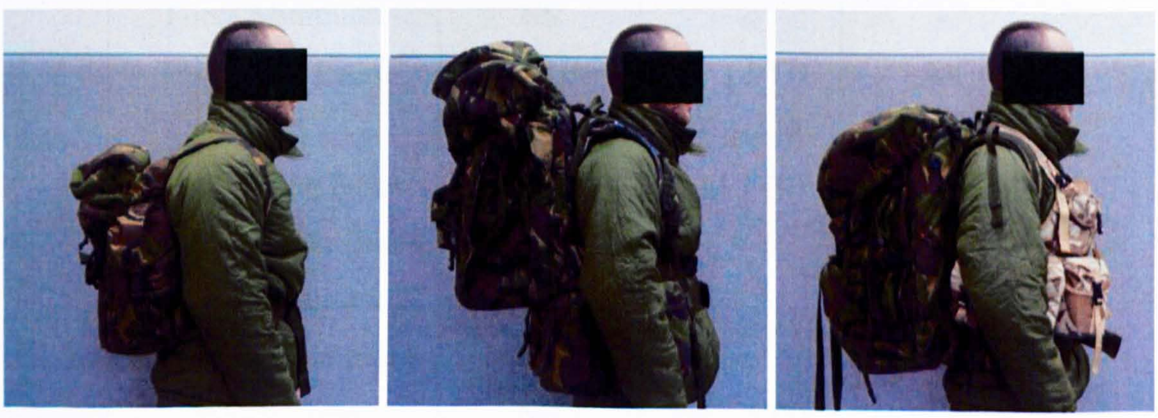


Figure 6.2: Backpack, Standard and AirMesh LCS (left to right respectively) when 24 or 32 kg were carried.

6.3.3 Parameters Measured and Data Analysis

All GRF parameters were collected, normalised and means calculated (as outlined in section 3.5.2) for every condition. As with the previous biomechanical studies only the 8 major GRF parameters were considered for analysis. The participant's kinetic data were normalised and expressed as Newton's per unit body mass ($N.BM^{-1}$), allowing direct comparison between participants. The data were normalised to system weight, which is the weight of the participant, clothes, boots and rifle. A MANOVA was used to determine differences between conditions, with a Tukey post-hoc test were used to compare the 3 LCS (standard, AirMesh and backpack) at the different carried loads.

6.4 Results

Results from the study showed that only the thrust maximum (aka force produced at toe-off) differed significantly ($p<0.05$) for the 3 LCS with the MANOVA (table 6.2). However, the Tukey post-hoc test highlighted significant differences between the 3 LCS at different carried loads, namely trends for changes to the maximum braking force and stance time with the 3 LCS. Important findings from the study summarised in table 6.2.

Table 6.2: Summary of load distribution results, * indicates significance.

GRF Parameter	MANOVA Significance	Overall Trend	At Which Load
Impact Peak	NS	-	-
Force Minimum	NS	-	-
Thrust Maximum	$p < 0.05$ *	BP ↓ STD	All
		BP ↓ AM	24 & 32 kg
Max Braking Force	NS	AM ↓ BP	32 kg
Max Propulsive Force	NS	-	-
Vertical Impulse	NS	-	-
Mediolateral Impulse	NS	-	-
Stance Time	NS	BP ↓ STD	24 & 32 kg
		AM ↓ All	8 kg

Table 6.3: Mean GRF parameters data for 3 LCS at 8, 16, 24 and 32 kg. * indicates significance ($p<0.05$) from Tukey post-hoc test, ^ indicates trend ($p<0.1$).

GRF Parameter	**8 kg**			**Significance**	**16 kg**			**Significance**
	Backpack	Standard	AirMesh		Backpack	Standard	AirMesh	
Impact Peak	1.376 (0.09)	1.356 (0.10)	1.372 (0.12)	NS	1.495 (0.13)	1.467 (0.11)	1.455 (0.08)	NS
Force Minimum	0.659 (0.07)	0.659 (0.06)	0.656 (0.05)	NS	0.714 (0.09)	0.705 (0.08)	0.734 (0.05)	NS
Thrust Maximum	1.308 (0.04)	1.344 (0.07)	1.328 (0.05)	BP ↓ STD ^	1.397 (0.08)	1.459 (0.07)	1.401 (0.07)	BP ↓ STD *
Max Braking Force	-0.278 (0.05)	-0.257 (0.04)	-0.267 (0.05)	NS	-0.309 (0.06)	-0.314 (0.09)	-0.302 (0.07)	NS
Max Propulsive Force	0.262 (0.03)	0.261 (0.03)	0.267 (0.03)	NS	0.282 (0.04)	0.289 (0.04)	0.287 (0.03)	NS
Vertical Impulse	1.185 (0.07)	1.192 (0.08)	1.164 (0.11)	NS	1.318 (0.04)	1.344 (0.14)	1.327 (0.11)	NS
Mediolateral Impulse	0.043 (0.01)	0.044 (0.01)	0.044 (0.01)	NS	0.047 (0.01)	0.047 (0.01)	0.049 (0.01)	NS
Stance Time	0.670 (0.02)	0.673 (0.02)	0.658 (0.02)	AM ↓ All ^	0.675 (0.02)	0.676 (0.02)	0.671 (0.03)	NS

GRF Parameter	**24 kg**			**Significance**	**32 kg**			**Significance**
	Backpack	Standard	AirMesh		Backpack	Standard	AirMesh	
Impact Peak	1.579 (0.12)	1.570 (0.11)	1.544 (0.16)	NS	1.689 (0.16)	1.681 (0.11)	1.685 (0.18)	NS
Force Minimum	0.783 (0.08)	0.752 (0.05)	0.761 (0.09)	NS	0.832 (0.12)	0.822 (0.07)	0.838 (0.07)	NS
Thrust Maximum	1.481 (0.09)	1.519 (0.06)	1.535 (0.07)	BP ↓ All ^	1.566 (0.11)	1.648 (0.08)	1.639 (0.14)	BP ↓ STD *
Max Braking Force	-0.328 (0.06)	-0.319 (0.05)	-0.319 (0.06)	NS	-0.374 (0.07)	-0.345 (0.06)	-0.341 (0.06)	AM ↓ BP *
Max Propulsive Force	0.299 (0.03)	0.298 (0.03)	0.300 (0.04)	NS	0.318 (0.04)	0.316 (0.03)	0.328 (0.04)	NS
Vertical Impulse	1.413 (0.05)	1.427 (0.07)	1.423 (0.09)	NS	1.494 (0.11)	1.537 (0.10)	1.503 (0.08)	NS
Mediolateral Impulse	0.050 (0.01)	0.048 (0.01)	0.046 (0.01)	NS	0.049 (0.01)	0.048 (0.01)	0.052 (0.01)	NS
Stance Time	0.680 (0.02)	0.693 (0.02)	0.685 (0.03)	BP ↓ STD *	0.682 (0.02)	0.699 (0.03)	0.688 (0.02)	BP ↓ STD ^

6.5 Discussion

The effect that altering the distribution of carried load within LCS has received limited attention in the relevant literature. This study utilised 12 different load and LCS combinations, and carried load in British military LCS. These factors make the current study both relevant and significant in aiding our understanding of the biomechanical effects of military load carriage. The most important findings from the study are described below.

1. A significant change in the thrust maximum was observed between the 3 LCS. More specifically, the backpack LCS produce a lower force compared to the standard LCS at all loads. Also, a trend was observed for thrust maximum in the backpack LCS to be lower than the AirMesh LCS at the higher loads.
2. Stance time was significantly lower in the backpack LCS compared to the standard LCS at 32 kg, with a trend to be lower at 24 kg. Also, a trend was present for the AirMesh LCS to produce a lower stance time to both the other systems at 8 kg.
3. Maximum braking force was significantly reduced in the AirMesh LCS condition compared to the Backpack LCS when carrying 32 kg.

6.5.1 Changes Observed to the Thrust Maximum

The thrust maximum (or force produced at toe-off) displayed an overall effect for significant differences between each of the 3 LCS, the post-hoc test also revealed differences between the loads. Figure 6.3 shows the backpack LCS condition resulting in 2 – 3% lower forces compared to the standard LCS at all carried loads, and around 4% reduction in force compared to the AirMesh LCS at the higher loads. This implies that shifting the CoM posteriorly by carrying load on the back reduces the force at toe-off. These differences observed may be equally attributed to the forward lean of the participant while walking with the loads as it is with the changes to the CoM. Forward lean is the body's way of balancing out the moments caused by adding additional load to the posterior of the body. The greater the load or the further away this load is placed from the body's neutral CoM, the greater the forward lean.

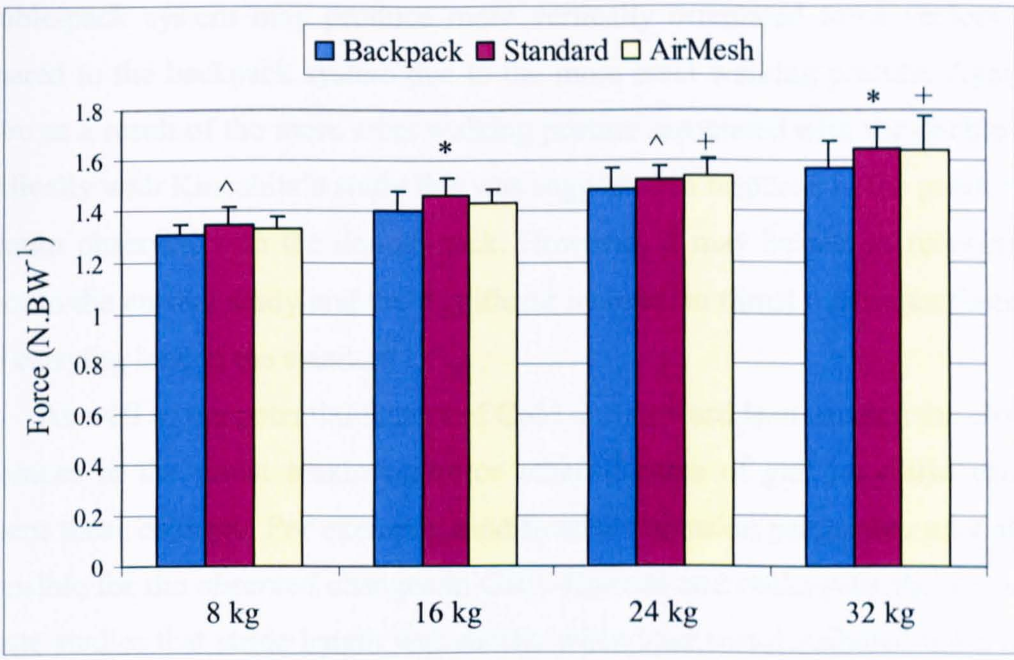


Figure 6.3: Mean thrust maximum value for LCS conditions against load, error bars represent standard deviation.

* indicates backpack significantly lower than standard LCS.

^ indicates trend for backpack to be lower than standard LCS.

+ indicates trend for backpack to be lower than AirMesh LCS.

It is reasonably well established that distributing load on both the anterior and posterior of the body reduces forward lean during load carriage (Kinoshita, 1985; Harman et al, 1994; Attwells et al, 2004; Fiolkowski et al, 2006). Kinoshita (1985) suggested that the inclined posture adopted with a backpack system appears to facilitate forward advancement of the body, while the double-pack system inhibits this advancement. Applying this idea to the results found with this current study implies that displacing the body's CoM posteriorly increases the forward lean, which in turn facilitates forward advancement. Thus reducing the forces needed to advance the body during mid-stance and into toe-off. This suggests that forward lean increases the passive momentum of the body resulting in reduced forces at toe-off. A notion supported in part with results from this chapter which showed significant decreases in force produced at toe-off when carrying loads in a military backpack. A similar principal was observed by Harman et al (2001), but instead of a lower thrust maximum they found the force minimum was decreased when the body's CoM was displaced further away from its natural position. Kinoshita (1985) also suggested that a double-pack system may produce more vertically orientated force vectors when compared to the backpack system due to the more erect walking posture. Again this may be as a result of the more erect walking posture associated with the double-pack. Specifically with Kinoshita's study this was suggested in response to the greater force minimum observed with the double-pack. However, it may be just as relevant with respect to the current study and the significant increase in thrust maximum force seen when carrying load in the standard LCS.

As well as the potential factors of CoM and forward lean causing the observed differences in the thrust maximum force other features of gait may also cause or augment these changes. For example, modifications to stride parameters may also be responsible for the observed changes in GRF. Harman and colleagues showed in two separate studies that stride length was shorter when load was distributed more evenly around the body compared to a more traditional backpack (Harman et al, 1997 and 2001). They suggested that an increased stride length is seen when the CoM is moved further away from its neutral position. A longer walking stride usually indicates that the foot is placed further in front of the body, an action which is associated with increased braking forces (Martin and Marsh 1992; Harman et al, 2001) and impact forces (Challis, 2001). In other words, longer stride lengths lead to greater force produced during the heel strike phase of the gait cycle. The inverse pendulum model suggests that passive momentum generated in the initial phase of a gait cycle is conserved. This in turn leads to reduced momentum being needed to advance the body during mid-stance and toe-off, in this circumstance leading to a reduction in the respective forces. This factor may also be responsible for the differences observed with respect to the thrust maximum with the current study.

In addition to the statistically significant differences observed between the backpack and standard LCS, a trend with the data was seen for the backpack LCS to produce lower forces compared to the AirMesh LCS at the higher loading conditions of 24 and 32 kg. The potential reasons put forward previously (forward lean and changes to stride parameters) are equally as relevant when considering the AirMesh and backpack LCS. It is however of interest that the AirMesh LCS does not produce significant differences compared to the backpack LCS, even though the difference in the CoM is more apparent than with the standard LCS.

6.5.2 Changes Observed to Stance Time

The 3 different LCS adopted during this study resulted in changes to the stance time, or length of time the right foot was in contact with the floor. The post-hoc test revealed that stance time for the backpack LCS condition was significantly shorter than the standard LCS condition at 32 kg, and a trend for a difference at 24 kg of carried load. A trend was also seen for the AirMesh to result in a shorter stance time compared to both the backpack and standard LCS when 8 kg were carried (figure 6.4). Of the five studies found to investigate the effects of load distribution on the kinetics of gait, only two (Kinoshita, 1985; Lloyd and Cooke, 2000) reported stance time as a parameter. Kinoshita's study found no significant difference in stance time when carrying either 20 or 40% of bodyweight in a backpack or double-pack. However, an observable trend in the mean was noted for the backpack condition to exhibit slightly longer single support times compared to the double-pack system. Lloyd and Cooke also noted a trend ($p=0.056$) for the double-pack to elicit a shorter stance time than a traditional backpack. Both these studies suggest that loading the body more evenly during load carriage leads to reduced single support times.

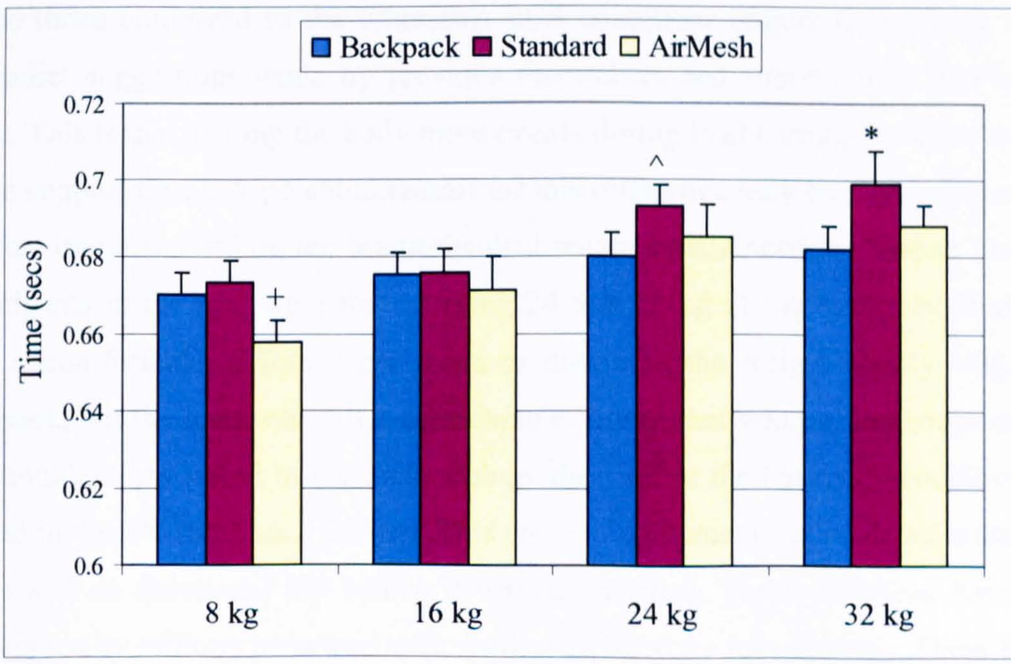


Figure 6.4: Mean stance time values for LCS conditions against load, error bars represent standard deviation.

* indicates backpack significantly lower than standard LCS.

^ indicates trend for backpack to be lower than standard LCS condition.

+ indicates trend for AirMesh to be lower than backpack and standard LCS.

Results from this current study showed that at 8 kg of carried load the AirMesh (or double-pack) LCS showed a trend to produce lower single support values compared to the other systems used (figure 6.4). This is in support of other research which also observed trends for double-packs to result in reduced stance times compared to traditional backpacks when walking (Kinoshita, 1985; Lloyd and Cooke, 2000). Neither of these two studies suggested potential mechanisms behind these observed trends. A potential reason for this observed difference was put forward in chapter 4, section 4.5.3. It was suggested that stance time is longer when carrying load in a backpack due to the extra time it takes to shift the CoM (which has been displaced further posteriorly with the backpack and standard LCS) over the base of support and into the propulsive phase. Another mechanism for longer stance times may be the need for extra stability. The body's CoM is displaced further away from its neutral position in the standard and backpack LCS conditions compared to the AirMesh LCS condition. Research suggests that when load is placed close to the body's CoM it results in an increase in static stability (Schiffman, 2004).

At the higher carried loads the backpack condition exhibited a trend for lower stance times compared to the other two LCS conditions (figure 6.4). These results contradict suggestions made by previous researchers and supported in part by this study. This is that loading the body more evenly during load carriage leads to reduced single support times. A potential reason for this difference may be psychological and comfort issues overriding the biomechanical parameters. Anecdotal reports from the participants in the trial were that carrying 24 and 32 kg in the backpack alone was very uncomfortable. Efforts were made to distribute the weight evenly within the backpack, but the load was still a considerable 'lump' that was pulling backwards on the shoulders. As stated in the methodology the load in the backpack condition was carried in the '90 short back Bergen. This piece of equipment has inadequate shoulder straps and no functional hip belt to distribute the load. These problems have been highlighted by military personnel with work conducted by Jones (2005). These factors will be considered further in chapter 9 of this thesis. These comfort factors may have combined to significantly change participant's gait cycle, thus overriding the biomechanical effects such as changes in the position of the boy's CoM or forward lean. A comparison of spatiotemporal parameters with this study may have highlighted a reduction in stride length and increase in stride frequency with the backpack LCS at heavy loads. This in turn may be an explanation for the reduction in stance time observed here, due to the fixed nature of the walking speed adopted. These factors may explain the discrepancy between the current study and the available literature, which suggests distributing the load more evenly results in reduced single support times. It is also worth noting that no significant differences have been observed within the literature, only trends.

6.5.3 Changes Observed to the Maximum Braking Force

Maximum braking force is the force that slows the body down during the initial part of the gait cycle and acts in the anteroposterior axis. The main interest with this parameter in respect to LCS design is that increased sheer forces that act on the foot will 'increase the probability of blisters during physical activity' (Knapik et al, 1997b). Foot blisters are the most common load carriage related injury and can also be debilitating (Knapik et al, 1992 & 1997a; Reynolds et al, 1999). Load carriage has also been shown to increase blister incidence independently to other factors, such as distance marched, physical fitness etc (Knapik et al, 1993; Reynolds et al, 1990). A potential reason for this was put forward by Knapik et al (1997a). This was that load carriage increases the pressure on the skin and causes more movement between the foot and boot through higher propulsive and braking forces (Kinoshita, 1985).

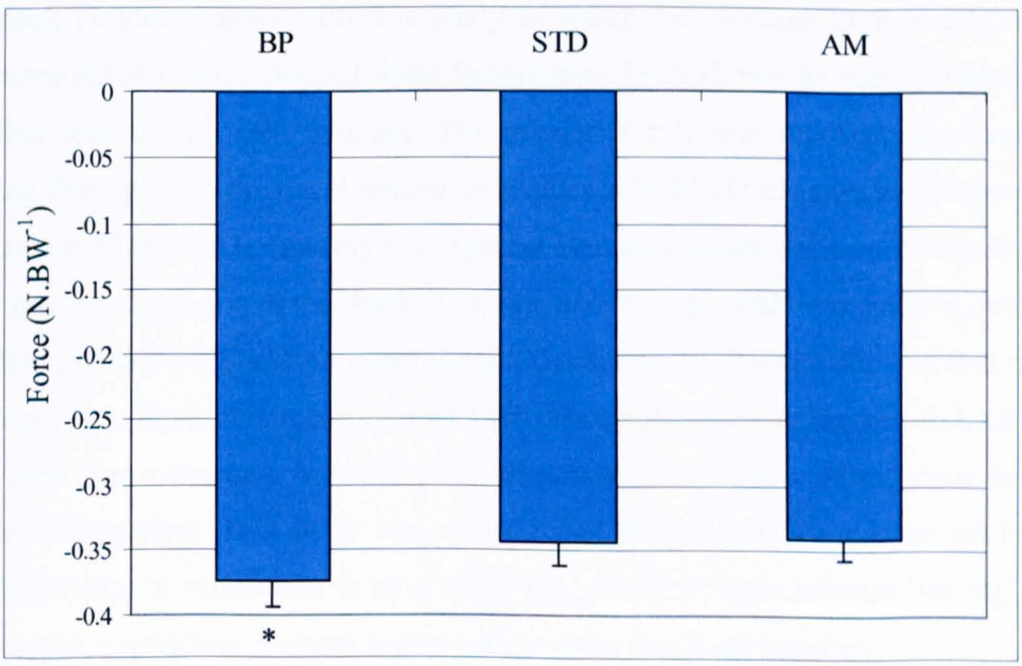


Figure 6.5: Mean maximum braking force for the LCS tested at 32 kg, error bars represent standard deviation. * indicates significant difference from other conditions.

Figure 6.5 shows the significant ($p<0.05$) increase in maximum braking force with the backpack condition compared to both the standard and AirMesh conditions at 32 kg. This increase in force is more marked than previous results in this chapter, with the backpack showing a 10% increase in maximum braking force compared to the other two LCS. This suggests that carrying load that is more evenly distributed around the trunk reduces such forces, this has been observed with other studies (Kinoshita, 1985; Harman et al, 2001). Factors given for this increase are as a result of the more erect walking posture with the double-pack producing more vertically orientated force vectors (Kinoshita, 1985) or due to an increase in stride length with a double pack (Harman et al, 1997 and 2001). Lloyd and Cooke (2000) published results that were in contrast to the above findings. They reported no significant differences with the maximum braking force with a backpack compared to double-pack, but instead increases to the maximum propulsive force. A suggestion put forward by the authors for the increase in propulsive force with the backpack condition was that this resulted from a decrease in forward lean through the stride cycle. They conclude that the greater the change in positive and negative forward lean (or greater range of motion of the trunk) observed in double-pack condition may lead to a difference in momentum of the upper body, which could reduce propulsive forces (Lloyd and Cooke, 2000).

The most likely reason for the increase in maximum braking force in the backpack condition seen with this study is either the increase in forward lean or increased stride length. Both of these factors have been shown by other studies to be possible reasons for such increase. The important role that increases in maximum braking force play in the development of blisters is highlighted again in another study by Knapik et al (1993). Twenty-one Special Forces soldiers performed 6 individual road marches carrying three loads (24, 48 and 61 kg) and two pack systems (a standard military LCS and an experimental double-pack). Results showed that blister incidence was lower when carrying 61 kg in the double-pack compared to backpack. Also seen was a decrease in lower back discomfort but subsequent increases in neck and hip discomfort. This study can confirm that the most likely mechanism behind this lower blister occurrence is as a result of a decrease in maximum braking force resulting in a reduction in sheer forces acting at the foot-boot interface.

6.6 Conclusions

Changing the distribution of load within a LCS had little effect on the GRF parameters of human gait. Despite this important findings were established, in particular the effect of heavy load carriage on maximum braking force. A 10% increase in maximum braking force was observed when carrying 32 kg in the backpack condition compared to the other two conditions used. This shows that distributing the load on the anterior and posterior of the body leads to a reduction in this force parameter. The importance here lies in the development of blisters as an increase in anteroposterior GRF have been linked to the increased development of foot blisters. The thrust maximum, or force produced at toe-off, was the only parameter to differ significantly between the 3 LCS adopted for the study. Displacing the body's CoM further away from its neutral position, as induced by the backpack LCS, resulted in a decrease in the thrust maximum force. Finally, stance time with the backpack LCS was shorter than in the other two conditions at the heavier carried loads. This may be a result of the uncomfortable nature of carrying such heavy loads in a backpack alone. The results from the study lead to the accepting, in part, of hypothesis 1.

The carriage of load in a double-pack has significant benefits when considering the kinematics and energetics of load carriage. In addition to these, the reduction of braking forces is a considerable benefit of carrying load in such packs. This leads to the accepting of hypothesis 2. Although the total load carried is the major cause of changes to gait patterns or increases in injury rates, the scientific testing of and development of future LCS can modify these risks. Particular focus should be placed on reducing the impact peak and maximum braking force, as these have the strongest and most viable links to the development of both acute and overuse injuries.

6.7 Limitations

As highlighted in the results relatively few differences with the GRF parameters were found with this study. This may be as a result of only 12 participants being recruited for the study, and not 15 as in previous studies (chapters 4 and 5). Power analysis conducted at the beginning of this thesis revealed 16 participants were required in order for potential differences to be highlighted. Unfortunately due to participant and time restraints only 12 participants were recruited for this current study. Other potential reasons for this may be the number of parameters measured, and therefore the need for a more general statistical test in the MANOVA and Tukey post-hoc tests. Not withstanding this, another factor could be that the LCS adopted for this study not distributing the load as evenly as custom built framed backpacks would. For example in the AirMesh LCS 32 kg condition, 12 of the 32 kg were placed on the front of the body, whereas with a purpose built frame this would have been 16 kg. The aims of the thesis have always been to focus on military LCS that are used or can viably be used by the UK military. Finally, the fact that few differences were found to GRF parameters with changing the load distribution is in agreement with other work published. This highlights the fact that total load carried may be the principal mechanism behind changes to gait patterns.

Chapter Seven – 3D, Bi-Lateral Gait Analysis of Military Load Carriage

7.1 Introduction

Chapters 4 to 6 of this thesis have involved the presentation of original and independent research investigating the effect of various load carriage parameters on ground reaction forces (GRF). The important effects of heavy load carriage, rifle carriage and load distribution on GRF parameters have been analysed. While GRF reflect the linear kinetics of force exerted on the ground by the foot, the measurement of angular kinetics reveals the magnitude of forces that act within the skeletal system at joint centres of the lower limb. This chapter is the final biomechanical study conducted for this thesis and represents a significant shift in the methodology used and data collected. As suggested by the chapter title 3D, bilateral gait analysis of load carriage was conducted. For this both the force plate and Coda Motion Analysis system were used. This enabled lower limb kinetic, kinematic and spatiotemporal data to be collected and relevant parameters measured. This data, in addition to that all ready collected, will enable a complete view of load carriage effects on the lower limb. This chapter alone represents a significant piece of work that, to the author's knowledge, has not been investigated before within the published load carriage literature. An aim of the current study was to establish benchmark data for 3D joint kinetics, as well as reviewing potential outcomes for injury rates.

The literature, which is briefly outlined in section 7.2, highlighted that there is no definitive effect of load carriage on many, but not all, of the kinematic and spatiotemporal parameters of human gait. Also, the biomechanical military load carriage literature is lacking in studies involving 3D joint kinematics and kinetics. The aim of this study was to extend the understanding these effects and benchmark unreported data. To achieve these aims and test the following hypothesis a laboratory based study was conducted using both the force plate and motion analysis systems.

H_1: Load carriage will induce altered joint kinematics.

H_0: Load carriage will not induce altered joint kinematics.

H_2: Spatiotemporal parameters will change with load carriage.

H_0: Spatiotemporal parameters will not change with load carriage.

H_3: Joint moments and powers will increase as additional load is carried.

H_0: Joint moments and powers will not increase as additional load is carried.

7.2 Background

The effects of load carriage on the principal kinematic parameter of trunk angle are well established, see section 2.9.1 of the literature review. Load carriage causes forward lean, and the greater the carried load the greater the forward lean. Of interest to this thesis is the effect of load carriage on lower limb kinematics. An increase in carried load has been shown to increase knee flexion at heel strike. This is suggested to be a protective mechanism to aid the absorption of forces produced during initial impact. Over the stride as a whole, studies have shown a decrease in knee RoM with increasing load. Changes to the hip and ankle angle have also been shown to occur but are less significant. The angle of pelvic tilt has been shown to increase as load is added. This may be considered to be a suitable means of inferring forward lean. Other kinematic parameters can be measured, these include angles of the upper body (shoulder, elbow and head angles) and the position of the CoM.

Spatiotemporal parameters of gait during load carriage have received mixed reviews within the load carriage literature, with the issues of fixed and free walking speeds and, military verses non-military personnel causing debate. The majority of the relevant literature is conducted at a fixed walking speed with military participants or with participants with load carrying experience. One universally observed gait alteration with load carriage is an increase in percentage (or absolute value) of the stride spent in double support. This has been suggested to be a protective mechanism by limiting the force needed to be absorbed by the lower limb, and increasing stability. Other changes may include a decrease in stride length and subsequent increase in stride frequency to maintain walking speed.

All studies that detail the effect of load carriage on joint moments (aka torque) show an increase in moments as load increased. These studies have also only investigated moments in the sagittal plane, i.e. flexion and extension. An unexpected result was that peak knee moments increased disproportionately compared to the carried load; ankle moments produced the opposite affect. No research to the author's knowledge has investigated 3D joint kinetics with respect to load carriage, or assessed the effect of load carriage on joint powers. Military load carriage in particular is rightly considered separately to other types load carriage (school children, backpackers and manual handling) due to the considerable weights carried and long duration of load carriage. However, other related literature should not be overlooked.

7.3 Methodology

7.3.1 Participants and Equipment

Ten male participants volunteered for the study (mass 79.2 kg ± 10.0 S.D., height 184.4 cm ± 6.3, age 29.3 years ± 9.9). The study complied with the conditions of the generic load carriage protocol (G03/P18), approved by the Loughborough University Ethical Advisory Committee. All participants who volunteered for the study had previous experience carrying backpacks and were right foot dominant and rear-foot strikers. A verbal and written explanation of the study was given, after which a health screen questionnaire was completed. Finally signed, informed consent was obtained from all participants before commencing the trial. Testing took place between 19th March and 21st April 2006 and was conducted in the Ergonomics Laboratory in the Wavy Top Building at Loughborough University.

The intension of this study was to collect 3D, bi-lateral gait analysis data. To achieve this both the force plate and Coda Motion Analysis System were required. In conjunction with this the Coda gait analysis package was used to allow 3D segmental gait analysis. This package used markers placed in predefined positions, both on the skin directly and on wands and frames (figure 7.1). The combination of all 3 pieces of equipment allowed 3D kinematics, kinetics and also spatiotemporal data to be collected. Section 3.4 of the methodology chapter outlines the gait analysis equipment used for this study in greater detail. To enable 3D data to be collected two Coda units were used and linked together. One was placed parallel to the force plate and collected sagittal plane data, the other was placed at the end of the walkway and focused on the frontal plane. Figure 7.2 shows the layout of force plate and Coda units used.

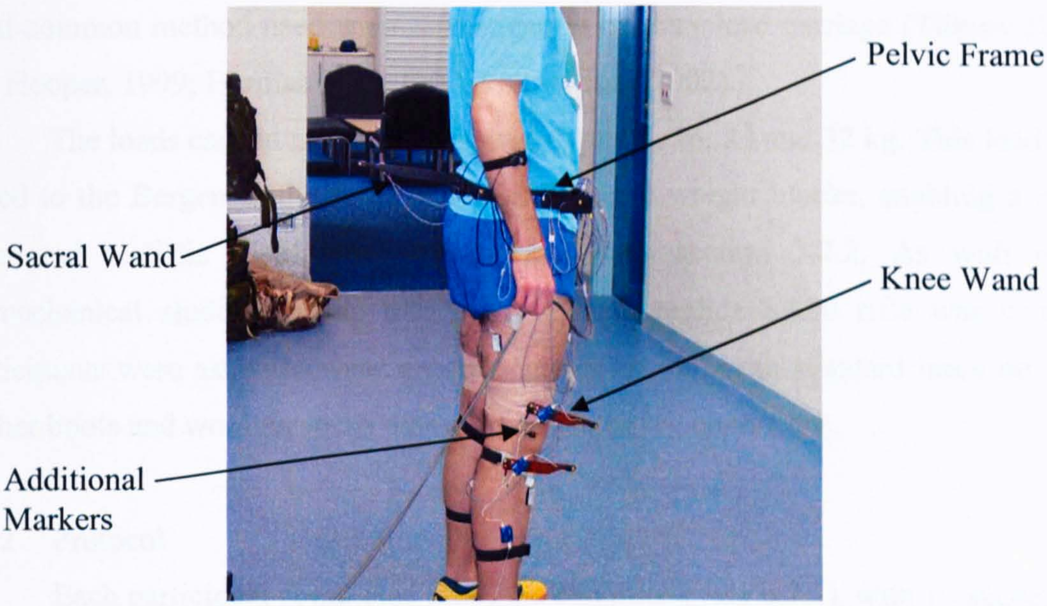


Figure 7.1: Example of the Coda gait package, with pelvic frame, knee and sacral wands and other markers.

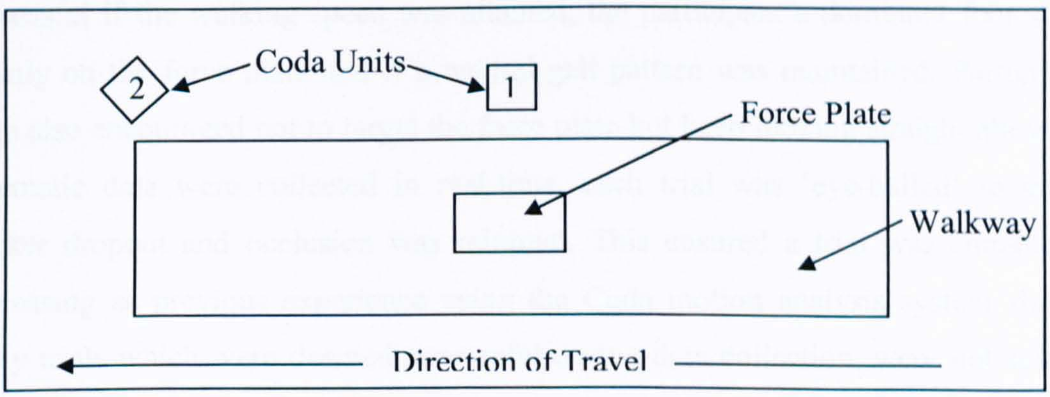


Figure 7.2: Experimental setup (excluding light gates).

A limitation with this study was that load could only be carried in the standard issue short back '90 pattern Bergen, and not as with previous studies of this thesis in webbing and/or Bergen. This was due to a pelvic frame being used which is essential for use with the Coda gait analysis package. This frame is necessary to calculate pelvis movements and is placed around the hips where the waist webbing would usually sit (figure 7.1). A principal aim of this thesis was to assess the biomechanical effect of load carried in military load carriage systems (LCS). Therefore, where possible load was carried in the same equipment and by the same method as it would be carried by members of the British armed forces. The current study is the one exception, given the need for the pelvic frame to be worn. However, the carriage of load in a backpack alone is not rare with biomechanical studies, and is probably the most common method used when investigating military load carriage (Tilbury-Davis and Hooper, 1999; Harman et al, 2000; Polcyn et al, 2002).

The loads carried in this current study were 8, 16, 24 and 32 kg. This load was added to the Bergen in the form of interchangeable weight blocks, enabling a more even and realistic distribution of the load, see section 3.2.2. As with other biomechanical studies in this thesis, a weighted replica SA80 rifle was carried. Participants were asked to wear non-restricted clothing, with standard issue military leather boots and woollen socks worn during all testing conditions.

7.3.2 Protocol

Each participant completed all of the conditions (table 7.1), with 10 successful trials required for each condition. The kinetic and kinematic data were sampled at 200 Hz and the target speed throughout was 1.5 $m.s^{-1}$ (± 5%). A trial was deemed successful if the walking speed was attained, the participant's dominant foot struck cleanly on the force plate and if a natural gait pattern was maintained. Participants were also encouraged not to target the force plate but keep looking straight ahead. As kinematic data were collected in real-time, each trial was 'eye-balled' to ensure marker dropout and occlusion was minimal. This ensured a trial was suitable for processing as previous experience using the Coda motion analysis system showed many trials which were deemed successful during data collection, were not suitable for processing as key makers may have dropped out at key times. Trials however were not assessed for their potential results just for quality of data. To ensure participants had familiarised themselves with the load and walking speed, an unlimited number of practice walks were allowed. The order in which the participants completed the conditions was randomised. Before each load carrying trial commenced the Coda gait package and markers had to be attached and joint dimensions taken, see section 3.4.3 of the methodology chapter for more details.

Table 7.1: Description of conditions used.

Condition	Description
Boot	Wearing non-restrictive clothes and military boots
Rifle	As boot, carrying replica weighted SA80 rifle
8 kg	As rifle, carrying 8 kg in Bergen
16 kg	As rifle, carrying 16 kg in Bergen
24 kg	As rifle, carrying 24 kg in Bergen
32 kg	As rifle, carrying 32 kg in Bergen

7.3.3 Parameters Measured and Data Analysis

Three-dimensional gait analysis enables numerous parameters to be measured, these include: ground reaction forces (GRF), joint kinetics and kinematics all measured in the 3 planes of movement (frontal, sagittal and transverse) and also spatiotemporal data. The parameters measured are summarised below, further details on the biomechanical parameters measured can be seen in section 3.6 of the methodology chapter. Table 7.2 gives a brief description of the terminology used.

GRF Data: No GRF data were analysed for this current study, GRF data were used to calculate the kinetic variables analysed.

Kinetic: Peak and mean positive and negative moment/power, as well as mean moment/power for each joint in all 3 planes of movement. Five parameters per moment/power, 3 planes per joint, 3 joints, total of 45 parameters for both joint moment and powers.

Kinematic: A total of 12 parameters were measured encompassing RoM of the ankle, knee, hip and pelvis in all 3 planes of movement.

Spatiotemporal: 4 parameters measured including: stride length, stride time, % stance and % double support.

Table 7.2: Description of terminology used when discussing the kinetic and kinematic data.

Joint	CODA Terminology	Movement	Plane of Movement
Ankle	Supination	Towards midline	Frontal
	Pronation	Away from midline	Frontal
	Planterflexion	Decrease angle	Sagittal
	Dorsiflexion	Increase angle	Sagittal
	Alignment	Rotation	Transverse
Knee	Varus	Towards midline	Frontal
	Valgus	Away from midline	Frontal
	Flexion	Decrease angle	Sagittal
	Extension	Increase angle	Sagittal
	Rotation	Internal or External	Transverse
Hip	Adduction	Towards midline	Frontal
	Abduction	Away from midline	Frontal
	Flexion	Decrease angle	Sagittal
	Extension	Increase angle	Sagittal
	Rotation	Internal or External	Transverse
Pelvis	Obliquity	Mediolateral tilt	Frontal
	Tilt	Anteroposterior tilt	Sagittal
	Rotation	Rotation	Transverse

Although GRF data were collected in order to calculate the joint kinetics, GRF data will not be discussed during this chapter. This is because chapters 4 – 6 have reviewed in-depth the effects of load carriage in military LCS on GRF parameters. This study involved the collection of a very significant amount of data without the addition of the GRF data. The kinetic data were normalised to body weight, with moments expressed as Newton-meters per kilogram ($Nm.kg^{-1}$) and power as Watts per kilogram ($W.kg^{-1}$). Kinematic data were not normalised, nor were the spatiotemporal data. Percentage stance and double support were calculated as a proportion of total stride time. A 10-trial mean was then calculated for each of the biomechanical parameters measured.

7.3.4 Statistical Testing

Due to the large number of parameters measured with this study numerous different statistical tests were used, with certain data sets lending themselves to particular tests. Potential differences within the kinetic data were established by conducting One-Way Repeated Measures ANOVAs, these were Bonferroni corrected for running multiple ANOVAs. Pair-wise comparisons determined significances between the loads. The spatiotemporal data were also assessed in the same way. Kinematic parameters were analysed using a MANOVA and Tukey post-hoc test. All of the parameters above were tested with the rifle, 8, 16, 24 and 32 kg conditions. The statistical testing was conducted in SPSS 12.0 for Windows and significance was accepted at $p \leq 0.05$, or its Bonferroni corrected equivalent.

7.4 Results

7.4.1 Kinetic Effects of Load Carriage

Appendix 7.1 and 7.2 show the raw data for the effect of load carriage on both joint moments and power. Table 7.3 shows the main and pairwise differences with the peak joint moments in the sagittal plane. These are the most frequently reported parameters in the related literature. Below is a summary of these finding and statistical significance highlighted:

Ankle: Both peak ankle planterflexor and dorsiflexor moments and power increased significantly with load. Very few differences were observed with the alignment movement with only the minimum moment changing. Peak and mean ankle pronation moment increased with load, as did the overall mean. Mean pronation and supination power values also increased with load.

Knee: Peak knee flexion moment and mean value increased with load, but only mean flexion power increased significantly. Peak and mean knee extension power increased with load, with only peak extension moment differing. Peak and mean knee varus moment and power increased with load, with little change with the valgus movement. All knee rotator moment parameters increased significantly with load, while no power parameters changed.

Hip: Both peak hip flexor and extensor moments increased with load; however, only mean extensor power showed an increase. Mean and peak hip adductor moment increased as did mean adductor and abductor power. Peak and mean maximum rotator moment increased with load, also observed were increases in maximum and minimum hip rotator powers.

Table 7.3: Summary of the main and pairwise effects with load to the peak joint moments in the sagittal plane.

Joint	Movement	Significant Effect	Pairwise Effect
Ankle	Planterflexion	$p < 0.001$ *	0 kg ↓ 8 - 32 kg
	Dorsiflexion	$p < 0.001$ *	0 - 16 kg ↓ 32 kg
Knee	Flexion	$p < 0.001$ *	0 - 8 kg ↓ 16 - 32 kg
	Extension	$p < 0.001$ *	0 kg ↓ 32 kg
Hip	Flexion	$p < 0.001$ *	0, 8, 24 kg ↓ 32 kg
	Extension	$p < 0.001$ *	0 kg ↓ 24 kg

In addition to the absolute changes to sagittal plane joint moments stated above, the percentage of increase from the control as load was added was also assessed (table 7.4). Each 8 kg increment in carried load between the conditions represented approximately a 10% increase in body-plus-backpack load. If all joint moments reacted the same they would bear an equal share of the increase in body-plus-backpack load. If this is the case we would expect a 10% increase in peak joint moments with each condition (i.e. 10% at 8 kg, 20% at 16 kg etc). This however is not the case, with the flexor (and planterflexor) muscles generally increasing at a greater percentage compared to their extensor counterparts. In addition the knee flexor moments increase disproportionately compared to the other two joints. At each condition, the knee flexor moments show a percentage increase that is larger than the 10% increase per condition expected (table 7.4). This culminates in a 57% increase in knee flexor moment at the 32 kg condition. The hip flexor and ankle planterflexors increase in a similar manor, with lower than expected increases as load is added.

Table 7.4: Percentage increase in peak sagittal moment from rifle condition with load.

	8 kg	16 kg	24 kg	32 kg
Hip Flexor	8.2	12.9	16.4	34.0
Hip Extensor	10.1	17.1	20.4	27.2
Knee Flexor	11.3	31.3	41.8	56.7
Knee Extensor	8.9	12.8	16.0	30.7
Ankle Planterflexor	9.0	13.6	22.0	25.7
Ankle Dorsiflexor	-0.9	3.0	4.3	20.3

7.4.2 Kinematic Effects of Load Carriage

Results from the kinematic data showed that RoM data for 5 of the 12 parameters measured differed significantly ($p<0.05$) as load was added to the backpack. It is worth noting again that this study did not only look at angles in the sagittal plane, but all 3 planes of movement. The significant differences observed were a decrease in knee flexion/extension and pelvis rotation RoM. Increases were also observed with adduction/abduction and rotation of the hip, and finally an increase in pelvis tilt with added load. These results are summarised in table 7.5 and raw data in appendix 7.3.

Table 7.5: Summary of the main and post-hoc kinematic effects.

Joint	Movement	Significant Effect	Increase / Decrease	Post-Hoc Effect
Ankle	Dorsiflexion/Planterflexion	NS	-	-
	Pronation/Supination	NS	-	-
	Alignment	NS	-	-
Knee	Flexion/Extension	$p < 0.05$ *	Decrease	0-16 kg ↑ 32 kg
	Valgus/Varus	NS	-	-
	Rotation	NS	-	-
Hip	Flexion/Extension	NS	-	-
	Adduction/Abduction	$p < 0.05$ *	Increase	0 kg ↓ 32 kg
	Rotation	$p < 0.05$ *	Increase	8 kg ↓ 32 kg
Pelvis	Tilt	$p < 0.05$ *	Increase	-
	Obliquity	NS	-	-
	Rotation	$p < 0.05$ *	Decrease	0 kg ↑ 24 kg

7.4.3 Spatiotemporal Effects of Load Carriage

The stride parameters measured in this study changed with added load. Significant overall effects of load were to result in a decrease in stride length, and an increase in percentage stance and double support. No difference was observed with stride time. Numerous pairwise were also noted. The increase in percentage stance time seen with load also indicates a decrease in percentage swing time, as the stride is either split into stance or swing phase. Conversely, there was no difference with stride frequency as this is the inverse of stride time. The results are summarised in table 7.6 and raw data presented in appendix 7.4.

Table 7.6: Summary of the main and pairwise spatiotemporal effects.

Stride Parameter	Significant Effect	Increase / Decrease	Pairwise Effect
Stride Time	NS	-	-
Stride Length	$p < 0.05$ *	Decrease	0 kg ↑ 24 kg
% Stance	$p < 0.05$ *	Increase	-
% Double Support	$p < 0.05$ *	Increase	0-16 kg ↓ 32 kg

7.5 Discussion

Due to the large volume of parameters measured and results achieved the discussion is split up into 3 main sections, the effect of load carriage on the kinetic, kinematic and spatiotemporal parameters. Firstly, the key findings from this study will be highlighted. Further detail relating the key findings to the literature and their subsequent importance will be assessed in the specific section of the discussion.

The method adopted for this study enabled 3D, bi-lateral gait analysis of load carriage to be conducted. To the authors' knowledge this has not been investigated before in the load carriage literature, and highlights the importance of this work. As may be expected, and has been shown in the load carriage literature, all sagittal plane kinetics increased with load carriage. Of specific interest to this thesis is the potential for injury caused as a result of load carriage. The limitations with all research of this nature are that actual scientifically proven links between changes in GRF or joint moments and subsequent impact on injury have not been established. However, the current reasoning within the scientific community is that excessive increases in peak and mean forces will increase the risk of acute and overuse injuries. Of further interest were the observed changes to joint kinetics at the knee. Results from this study show that the knee bears a disproportionate share of the burden from increasing load. Also, observed was a significant increase in all of the kinetic parameters measured regarding knee rotation. These factors may lead to an increased risk with load carriage for the development of overuse injuries at the knee. Spatiotemporal parameters also changed with increasing load carriage. Effects seen were an increase in the percentage of stride time spent in stance and double support and a decrease in stride length. These 3 effects could all be mechanisms to increase the stability of the walking individual. Key kinematic differences with load carriage were an increase in pelvis tilt, the author puts forward that this may be an alternative method of measuring forward lean. Other important differences observed were a decrease in knee RoM and increases in hip abduction and rotation.

7.5.1 The Effect of Load on Kinetic Parameters

As mentioned in section 7.2 at the beginning of this chapter, no studies were found to have examined 3D joint kinetics within the load carriage literature, with previous studies having focused on movement in the sagittal plane. In addition, the majority of studies only measure peak kinetics and not mean values. Finally, no studies were found detailing changes to joint powers with load carriage. For these reasons the first part of the discussion will focus on peak joint moments in the sagittal plane.

Peak Joint Moments in the Sagittal Plane

All peak joint moments measured in the sagittal plane increased significantly ($p<0.05$) as load was added to the body (table 7.3). Peak ankle planterflexion moment (which occurs just before toe-off) is considerably greater than its dorsiflexion counterpart (occurring just after heel strike). The same is true for the hip, with flexion moments greater than extension. Peak hip flexion moment occurs at heel strike and extension moment at toe-off. The knee is somewhat different with relatively similar peak extension and flexion moments. Peak extension moment occurs very rapidly after heel strike, as the foot initial contact is during extension, with a smaller peak occurring again at toe-off. Peak flexion moment occurs just after heel strike, and coincides with both maximum knee flexion during stance and the impact peak GRF parameter.

Figure 7.3 shows the increase in hip and knee flexion and ankle planterflexion peak moments, with figure 7.4 illustrating peak extension and dorsiflexion moments. This increase in sagittal plane joint moments has also been found in pervious studies (Harman et al, 1992; Han et al, 1992a; Quesada et al, 1996; Harman et al, 2000). The comparison of recorded values for joint moments observed with this current study to those within the literature is not possible. Only one of the above studies presents any joint kinetic data, with this being presented in a different format (rad.kg^{-1}). The key principal however is the significant increase with all joint moments as additional load is carried. Worth noting is the comparatively small ankle dorsiflexion moments observed in figure 7.4. These moments are between 10 and 15% of their planterflexion counterparts. This may reflect the passive nature of ankle dorsiflexion during walking. This movement does not give momentum to the gait cycle, but just facilitates the transfer of the body's CoM over the base of support. Table 7.4 also illustrates that the percentage increase in peak ankle dorsiflexion moment does not increase until the heaviest load of 32 kg was carried. Also, the knee does not show as greater decrease in peak moment when in extension compared to the other joint. Peak knee flexion moments are approximately the same as those produced during extension. This indicates the importance of both the quadriceps and hamstrings in the human gait cycle. Peak hip flexion moments were the largest of all the joints, at between 2 and 3 $Nm.kg^{-1}$. This may indicate the increased emphasis on the hip muscles to generate the force necessary to progress the body during the gait cycle.

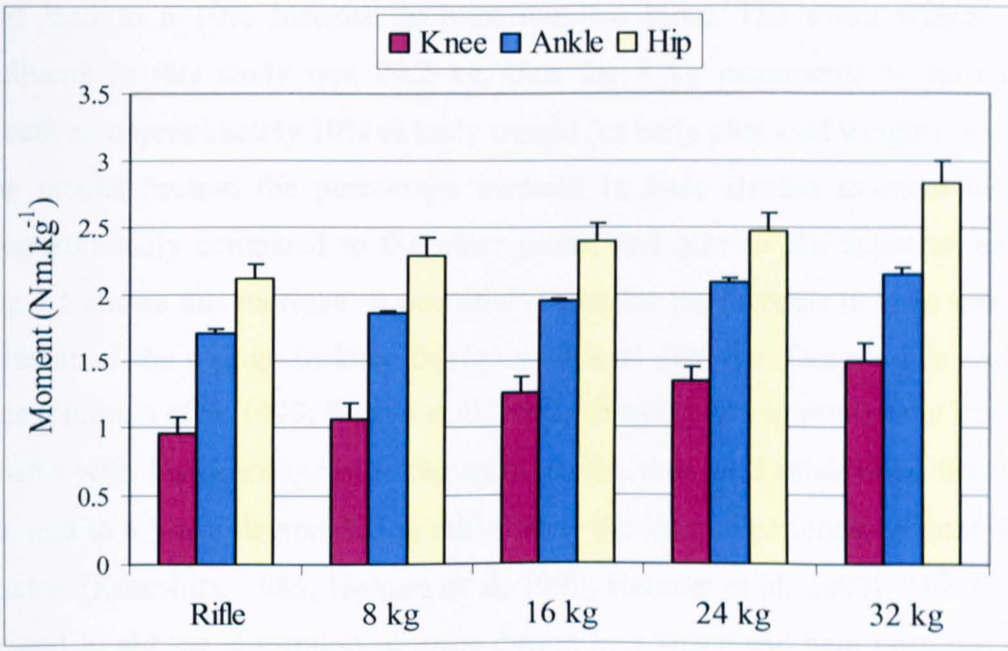


Figure 7.3: Change in mean peak joint flexion and planterflexion moment with load, error bars represent standard error of the data.

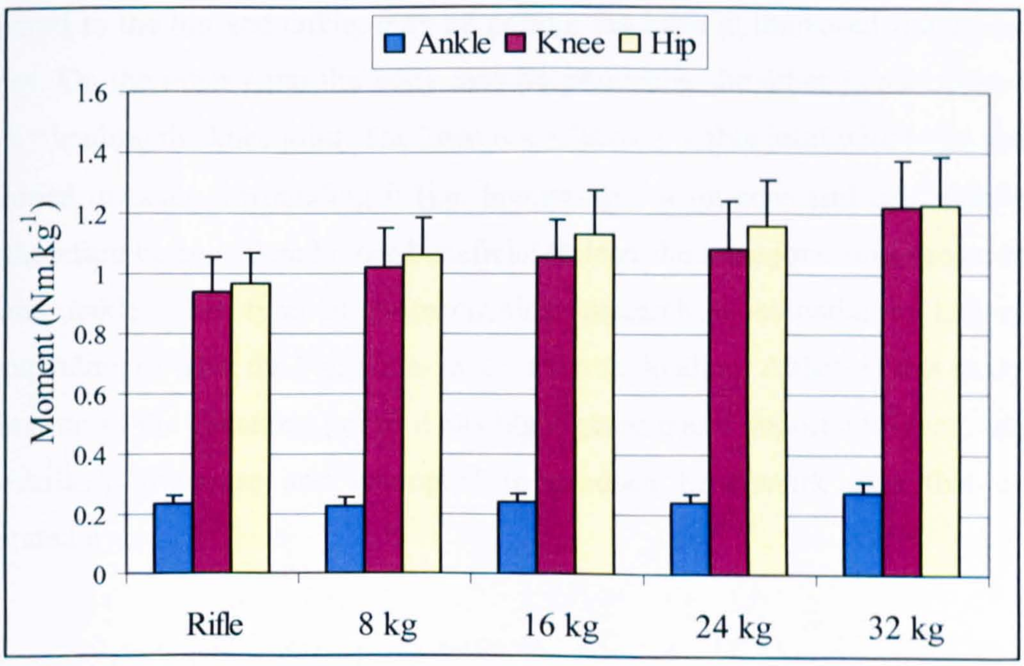


Figure 7.4: Change in mean peak joint extension and dorsiflexion moment with load, error bars represent standard error of the data.

In addition to the absolute changes in sagittal plane joint moments discussed above, percentage increases from the rifle condition were also examined. This indicates the additional force that is applied to a joint during load carriage, and is as a direct result of the added load. It could be expected that 10% increase body weight should lead to a 10% increase in joint moment force. The mean weight of the participants in this study was 79.2 kg, thus the 8 kg increments in carried load represent an approximately 10% in body weight (or body plus load weight). As shown in the results section the percentage increase in knee flexion moment increased disproportionately compared to the other joints, and also to the expected increase. Figure 7.5 shows this increase. A potential reason for the increase in knee moment is as a result of the change in knee flexion with load carriage. Despite this and other studies (Harman et al, 1999; Polcyn et al, 2002) showing that sagittal plane knee RoM decreases with load carriage over the entire stride, it is well established that at heel strike, and to a lesser degree during mid-stance, the knee experiences greater degrees of flexion (Kinoshita, 1985; Holmes et al, 1999; Harman et al, 2000). This has been suggested to aid the absorption of force during heel strike and help keep the body's CoM closer to the ground. This increased knee flexion will lead to greater moments experienced at the knee, as observed with the current study.

The fact that the knee is taking a disproportionate share of the increase in load, compared to the hip and ankle, may be putting the knee at increased risk of overuse injuries. On the other hand the body may be protecting the other joints of the lower limb by loading the knee joint. The knee is a relatively stable joint with large and well developed muscles surrounding it (i.e. hamstrings, quadriceps and calf muscles). It may therefore be considered more beneficial to load the knee joint thus protecting the hip and ankle. This type of biomechanical research is essential in helping the understanding of what the body does under external loading. Although this study does not answer all the questions posed it has highlighted many important issues, added to the available literature and attempted to produce benchmark data that can be elaborated upon.

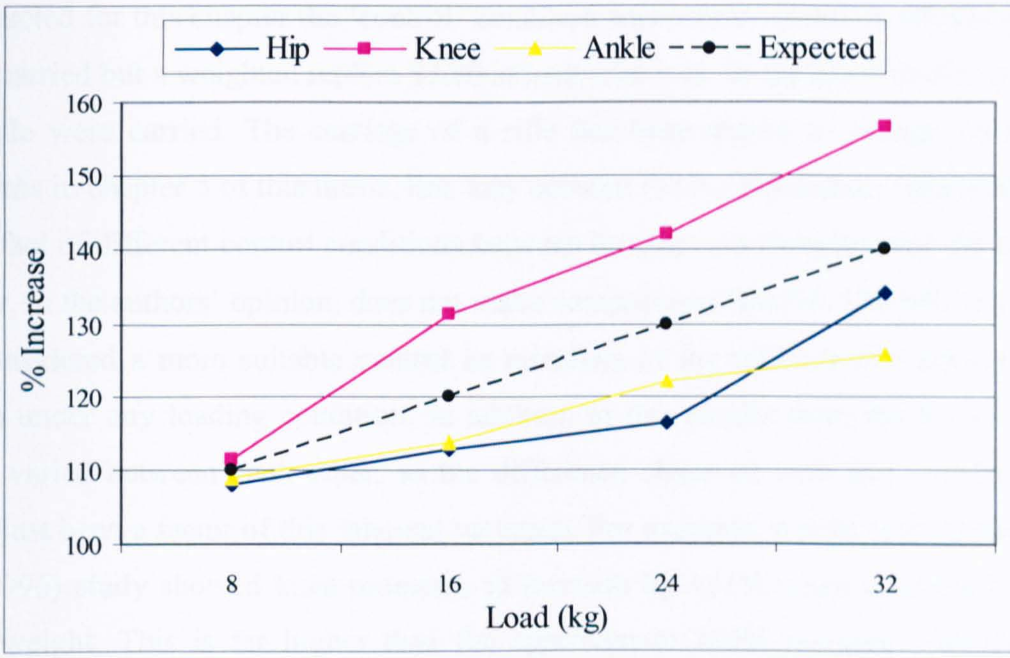


Figure 7.5: Percentage increase in mean sagittal joint moments from rifle condition against load. Black dashed line shows expected increase in moment if proportional to load.

Within the literature, results for percentage increase in joint moments from control condition are extremely varied. Table 7.7 shows these differences from the 3 studies available. The general trend observed in table 7.7 is that knee joint moments in the sagittal plane increase to a greater degree under loading compared to the hip and ankle joint. This confirms the findings from the current study.

Table 7.7: Percentage increase from a 'control' condition for lower limb joint moments measured in the sagittal plane. Results from the literature and current study.

Study	Load	% Increase in Joint Moment from Control		
	(% BW)	Knee	Ankle	Hip
Han et al (1992)	49%	98%	37%	107%
Quesada et al (1996)	30%	151%	28%	-
Harman et al (2000)	49%	104%	38%	47%
Current Study	40%	57%	34%	34%

Values regarding percentage increase from control condition in the knee and hip with the current study were consistently lower than with the other studies mentioned above. This may be as a result of the different 'control' conditions from which the increases were calculated from. The difference being that with the study conducted for this chapter the 'control' condition was a rifle condition, where no load was carried but a weighted replica SA80 assault rifle was. In the other studies no load or rifle were carried. The carriage of a rifle has been shown to change basal gait patterns in chapter 5 of this thesis, this may account for the differences observed here. The fact of different control conditions between the relevant literature and the current study, in the authors' opinion, does not make comparisons invalid. The rifle condition is considered a more suitable control as members of the military will always carry rifles under any loading condition. In addition to this results from the literature are very varied between each other, so the difference observed with this current study may just been a factor of this inherent variation. For example, results from Quesada et al (1996) study showed knee moments to increase by 151% when carrying 30% of bodyweight. This is far higher than the approximate 100% increase with 49% of bodyweight (Han et al, 1992a; Harman et al, 2000).

Various implications arise from the findings reported above can be drawn. The principal idea being that the muscles that generate moments at the knee assume a disproportionate share of the burden associated with load carriage. Quesada et al (1996) say that this suggests that military personnel exhibit substantial compensations during marching to accommodate their backpack load. It may also be reasonable to assume that such compensations may contribute to overuse injuries, as any deviations from natural gait patterns can be considered sub-optimal. Also seen was a significant increase in sagittal plane joint moments with increasing load carriage. Many studies suggest that the increases in joint moments are a risk factor for the development of overuse injuries as a result of heavy load carriage (Quesada et al, 1996; Harman et al, 2000; Polcyn et al, 2002). The implications of these results to the thesis are that they highlight potential areas for concern (e.g. moments of the knee), corroborate previous findings and finally present data which add to the pool of research relating to military load carriage.

Other Joint Moments in the Sagittal Plane

As described above peak sagittal plane joint moments all increased with load carriage. Changes to the mean flexion and extension (and planterflexion and dorsiflexion) moments, and overall mean joint moments also showed some interesting differences. Of particular interest is the effect of load on the overall mean joint moment, as this indicates which movement (either flexion or extension) is the more dominant and produces the greatest moments. The overall mean sagittal plane hip moment showed no difference as load was added. Although always positive, showing greater moments produced during flexion than extension, it did not increase significantly with load. This implies that both flexion and extension hip moments increased at the same rate as each other, as no changes in the mean values were observed. Both knee and ankle overall mean moments increased significantly ($p<0.05$) with load. This shows that knee flexion and ankle planterflexion are the dominant movements and moment generators for their respective joints.

Joint Moments in the Frontal Plane

So far this discussion has only focused on moments in the sagittal plane. However, a main aim of this study was to examine moments in all 3 planes of movement. This next section will discuss results from joint moments in the frontal plane. The frontal plane concerns movements towards and away from the midline of the body, i.e. hip abduction and adduction; knee valgus and varus; ankle pronation and supination.

A clearly observable pattern was present with all joint moments in the frontal plane. This was that all measured moments that moved the joints towards the midline of the body increased significantly ($p<0.05$) as additional load was added. This included the peak and mean moments for hip adduction, knee varus and ankle pronation, as well as overall mean values. No difference was observed with the peak or mean values relating to movements away from the midline of the body (appendix 7.1). Figure 7.6 shows the significant increase in peak moments for hip adduction, knee varus and ankle pronation with load.

Patterns of change in joint moments of the frontal plane all follow similar lines in their graphical outputs, the joint moment-time history. The ankle, knee and hip joint moments all display a duel peaked pattern similar to that of the GRF-time history. These peaks occur just after heel strike and before toe-off. Results from this study show that with the knee and hip moments either the first (heel strike) or second (toe-off) peak can be the larger. There appears to be great intra and inter participant variation as to which peak is of the greatest magnitude; however, both peaks are always relatively similar in magnitude. The exception to this is the ankle joint where the second peak is always of greater magnitude than the first.

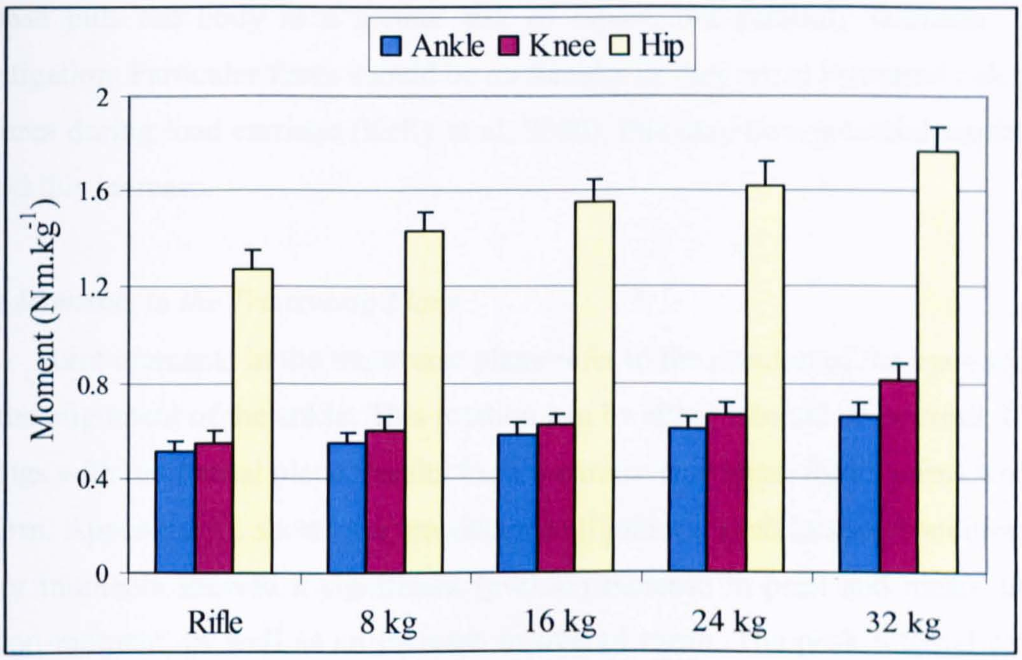


Figure 7.6: Mean peak joint moments acting towards the midline of the body against load, error bars represent standard error of the data.

The statistically significant increase in joint moments of the frontal plane has not been reported previously in the literature. The fact that peak moment values coincide with peak GRF values implies that a large element of the force transmitted from the floor upwards passes through the joints of the lower limb. It may be expected that some attenuation of forces is observed as it transmits up the limb, as seen with joint reaction forces (Polcyn et al, 2002). However, with moments this is not the case as hip joint moments are consistently larger than moments of the ankle and knee. Other factors for the increase in frontal plane joint moments observed with load carriage may be of stride parameters and kinematics. A greater step width has been observed with increasing load carriage (Kinoshita, 1985), this leads to an increase in the angle of the hip (see section 7.5.2). Increasing RoM of hip and a greater horizontal transfer of the weight across the base of support with larger step width may account for the comparatively large increase in peak hip adduction moments seen in figure 7.6. As mentioned previously the peak ankle pronation moment was generated just before toe-off. This shows that greater pressure is placed on the ankle pronator during push off compared to landing. The implications of this are that mechanisms aimed at increased stability by widening the base of support of the body during load carriage, may actually be increasing the hip moments in the frontal plane. It is not known if this increase puts the body at a greater risk of injury, but certainly warrants further investigation. Particular focus should be on females as they are at increased risk of hip fractures during load carriage (Kelly et al, 2000), this may be a potential mechanism behind this increase.

Joint Moments in the Transverse Plane

Joint moments in the transverse plane refer to the rotation of the knee and hip, and the alignment of the ankle. This rotation can be either internal or external. Unlike findings with the frontal plane, results from the transverse plane for all joints were not uniform. Appendix 7.1 shows the raw data for all joints at each loading condition. Hip rotator moments showed a significant ($p<0.05$) increase in peak and mean internal rotation moment, as well as an increase in overall mean. The peak internal rotation moment of the hips occurs just after heel strike, and may be a way of accommodating a lowered CoM (Harman et al, 2000) with increasing load carriage. This increase in internal rotation moments may also be a result of a decrease in joint stability in that particular plane compared to others. No differences were observed with external hip rotation moments.

Changes to the rotational moments of the knee were most marked. All parameters measured showed statistically significant changes with increasing load carriage (appendix 7.1(b)). These included peak (and mean) external knee rotation. External rotation of the knee occurs almost instantly after heel strike, and may be a response from the twisting of the tibia during foot impact. Internal knee rotation displayed the greater changes with peak, mean and overall mean values increasing significantly with load carriage. Peak internal rotation occurred at toe-off and again may be a function of a wider step width. The main concern with increased rotational moments at the knee joint is the greater risk of injury that is associated with load carriage. It is plausible to assume an increase in peak external rotation may increase the risk of acute injury to the knee. If peak moment during initial impact exceeds that of the tibial collateral ligament or posterior cruciate ligament, an acute injury of either a rupture or tear may occur (assumption adapted from Neely, 1998). Carrying heavy loads will also put excess pressure on an unstable joint. Once the CoM is over the base of support and both feet are in contact with the ground, the body is at optimal stability. Here the risk of falling or acute injuries is reduced; however, overuse injuries now become a realistic problem. An increase in internal rotational moments of the knee may increase wearing of the menisci of the knee and joint degradation. Again it is unknown if these limits are within the functional capacity of a joint, and the difference between statistical and clinical significance is again at the heart of establishing links between biomechanical and injury research.

Finally, we consider the ankle. Only the peak minimum ankle alignment moment (which can be seen as an external rotation moment of the foot) changed with load carriage. A significant ($p<0.05$) decrease in peak minimum value was observed, this equates to greater external rotation. This occurred at toe-off and due to the fixed position of the foot when in contact with the floor is a product of internal knee rotation twisting the tibia. This was the only ankle parameter to alter with load carriage, and of comparatively little interest.

Effects of Load Carriage on Joint Power

As mentioned previously the effect of load carriage on joint power has not been described within the load carriage literature. Also, power analysis of gait is not frequently conducted even with clinical gait studies. Finally, the joint power data collected via Coda was more erratic and sensitive to marker drop out compared to the moment data. This was characterised by high inter and intra-participant variation, which is reflected in the considerably higher standard deviations. This observation was particularly with respect to the peak values, but less so for the means. For these reasons this section will only describe the results found with the current study.

Joint powers did not seem to follow observable patterns as with the moment data. This is with the exception of the anticipated increases in joint powers in the sagittal plane as load is added. The greatest number of significant differences were seen with the mean data rather than the peak values. Twelve of the mean parameters showed significant differences, with only 6 for the peak parameters. This was out of a potential 18 for both. This may be as a direct result of the high standard deviation and variation within the peak values.

Joint power in the frontal plane showed significant ($p<0.05$) increases in both mean hip abductor and adductor joint power, but not with the peak values. The same was seen with the knee varus and valgus, and ankle pronation and supination power.

Sagittal plane joint power again showed varied results. All of the measured parameters for ankle joint power increased significantly with load, including the overall mean. Like with ankle moments this indicates that ankle planterflexion is the dominant movement, this increase in peak values again happens just before toe-off. Only hip extension mean power increased with load carriage. At the knee peak flexion power increased, as did mean flexion and extension power.

Joint power in the transverse plane showed some of the more interesting results. None of the measured parameters for either knee rotation or ankle alignment differed with load carriage. However, both peak internal and external hip rotation power increased as carried load increased. Also, seen was an increase in mean external rotation. Overall mean hip rotation power decreased significantly ($p<0.05$); however, this was only significant between the 32 kg and all other conditions. This may indicate measurement artefact, or that heavy load carriage induces far greater external hip rotation at toe-off.

The quality of the data and subsequent results make drawing meaningful conclusions from the power data very difficult. This may be why power data is lacking within the relevant literature. The key difference was a significant increase in all joint powers of the lower limb when measured in the sagittal plane with the addition of load.

7.5.2 The Effect of Load on Kinematic Parameters

This following section will discuss the results from the lower limb kinematic data already presented. It will evaluate the effects of load carriage on 3D joint kinematics, and where applicable relate current findings to the literature. Findings will be discussed by joints, with the RoM of these joints being the principal variable of interest. Kinematic parameters selected were automatically measured by the Coda Motion Analysis system and gait analysis package. The joint angles were measured in all 3 axes and derived from pre-set formulas within the Coda package. The makers used to define the angles are shown in figure 7.7.

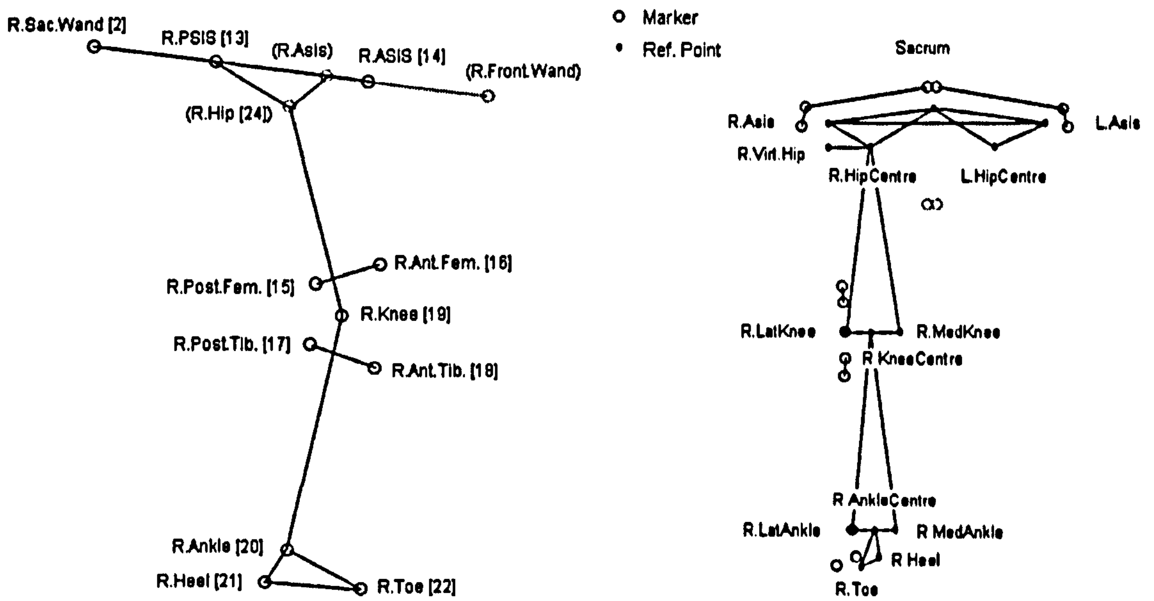


Figure 7.7: Right leg marker positions and joints and segment derived from these markers, taken from CodaMotion V6.64 user guide.

Ankle Angle

It is apparent from reviewing the data from this study that peak ankle dorsiflexion (or maximum ankle angle) occurs at the GRF parameter of thrust maximum. This is where the knee is furthest over the standing foot as the lower limb prepares to move into the swing phase of gait. Peak planterflexion (or minimum ankle angle) occurs at toe-off, here the foot planterflexes to aid the forward propulsion of the body. A second peak of ankle planterflexion is also observed, this occurs just after heel strike and is between 5 and 10 degrees less than the actual peak. Peak ankle planterflexion/dorsiflexion, supination/pronation and alignment angles reveal very little, with very consistent patterns of RoM.

As can be seen in table 7.5, increasing carried load had no effect on ankle kinematics with none of the planes of movement showing observable difference. This is supported by other studies that found no significant differences in sagittal plane ankle kinematics with load carriage (Harman et al, 2000; Attwells et al, 2006). This lack of difference may be due to the ankle's relatively small RoM during normal unencumbered walking. With military testing in particular, the ankle angle may be restricted further by the wearing of military boots which lace-up above the ankle. These boots give added stability to the ankle and aim to reduce the incidence of breaks and strain in the ankle joint.

This current work and the studies mentioned above measured RoM over the entire stride. Differences have been observed when considering the ankle angle during the different phases of stance. Kinoshita (1985) noted increased dorsiflexion in the early mid-support phase (impact peak to force minimum) as load increased. This resulted in the foot being 'rotated anteroposteriorly around the distal end of the metatarsal bones for a longer period of time when the heavier load was carried.' This was suggested to expose the metatarsal bones to greater mechanical stress for prolonged periods of time. It has also been noted that greater dorsiflexion of the ankle is needed to assist knee flexion, and aid the smooth transfer of the system weight in the forward direction during the early mid-stance of gait (Kinoshita, 1985). This suggests that knee bend aids absorption of impact forces by the body, but this in turn places the foot at an increased risk of stress fractures.

Knee Angle

Maximum knee flexion occurs during the swing phase of gait, at around 70% of the stride. This is when the knee is at its most bent in order to avoid contact with the ground during swing. The knee then straightens to be in an almost fully extended position for heel strike. Maximum knee extension arises at either just before heel strike or at thrust maximum, when the limb is almost fully extended. A second period of knee flexion is seen after heel strike during the impact peak GRF parameter. This second flexion peak is thought to aid the absorption of impact forces during heel strike (Kinoshita, 1985; Holmes et al, 1999; Harman et al, 2000).

Results from the study showed that the RoM of knee flexion and extension in the sagittal plane decreased as additional load was carried. Figure 7.8 indicates that although a main effect of load was observed, knee RoM does not start to decrease until the heavier loads are carried. This significant ($p<0.05$) difference was noted between the rifle, 8 and 16 kg conditions compared to the 32 kg loading condition. The RoM of flexion and extension of the knee decreased from 66.58 (± 1.9) in the rifle condition to 64.23 (± 1.6) in the 32 kg condition. The decrease in RoM is equally attributed to an increase in the minimum and decrease in the maximum knee angle. Over the entire stride the following studies showed a significant decrease in knee angle range of motion with increasing load (Harman et al, 1999; Polcyn et al, 2002) and a trend decrease (Harman et al, 2000). Ghori and Luckwill (1985) support this and showed that loads of 20, 30, 40 and 50% bodyweight carried in a backpack reduced knee flexion during the swing phase of gait.

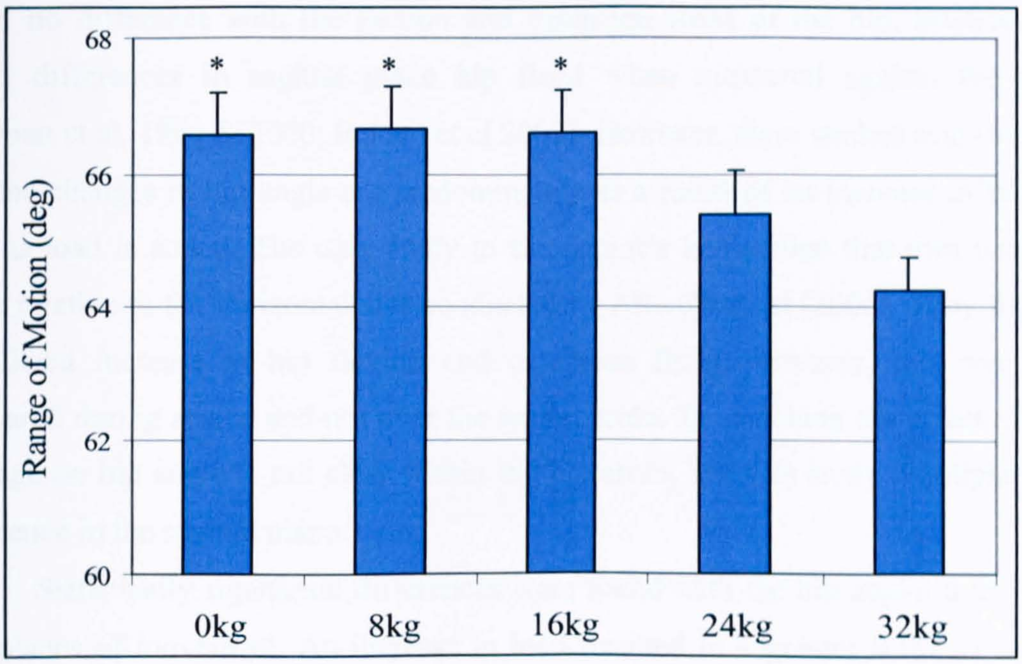


Figure 7.8: Change in mean sagittal knee angle RoM with load, error bars represent standard error of the data. * indicates significant difference from 32 kg condition

The reduction in knee RoM may not necessarily be a negative aspect of load carriage. The reduction of knee flexion during the swing phase will not place additional stress on the body or increase injury risk. The only possible issue may be that the foot is not lifted as high off the ground, this may increase the likelihood of tripping or catching the foot on uneven terrain. The main biomechanical issue with knee RoM is the increased flexion with increasing load just after heel strike (Kinoshita, 1985; Holmes et al, 1999; Harman et al, 2000). This increased knee flexion, along with the muscular system of the thigh, functions as a shock absorber and allows, in part, for the smooth transfer of the system weight to the ground (Kinoshita, 1985). Harman et al (2000) state that greater knee flexion helps keep the CoM lower, thus increasing stability as load increases. As was detailed previously in the chapter the greater knee flexion experienced during load carriage may increase the long term overuse injury risk, especially at the foot. The mechanisms behind this potential risk are an increase in time that the knee joint is exposed to high forces and increasing the moments produced.

Hip Angle

When the hip angle is measured relative to the horizontal, maximum hip flexion occurs around heel strike and maximum extension around toe-off. This study found no difference with the flexion and extension RoM of the hip. Studies have found differences in sagittal plane hip RoM when measured against the trunk (Harman et al, 1999 & 2000; Polcyn et al 2002). However, these studies acknowledge that the changes in hip angle are predominately as a result of an increase in forward lean as load is added. The only study to the author's knowledge that measured hip angle relative to the horizontal was conducted by Attwells et al (2006). They found a significant increase in hip flexion and extension RoM; however, this was only measured during stance and not over the entire stride. To conclude the effect of load carriage on hip angle is not clear within the literature, and this study highlighted no difference in the sagittal plane.

Statistically significant differences were found with the hip angle in the other two planes of movement. An increase in load resulted in a greater RoM of the hip angle in the frontal (abduction/adduction) and transverse (rotation) plane. As mentioned previously no study to the author's knowledge has investigated the effect of load carriage on 3D joint kinematics. Literature on 3D gait analysis is available mainly from a clinical setting and in particularly with persons with cerebral palsy.

The significant increase in hip angle in the frontal plane (figure 7.9) is equally attributed to insignificant trends for an increase in both peak hip abduction and adduction. The increase in peak hip abduction occurs at heel strike when increasing load carriage resulted in a less vertical femur. This may be attributed to an increase instep width (or wider base of support) which has been suggested to increase stability. Step width was not measured with this current study; however, Kinoshita (1985) noted an increase in step width when carrying 40% bodyweight in a backpack. Other well established effects occur to increase stability as carried load increases like an increase in double support (Ghori and Luckwill, 1985; Kinoshita, 1985; Martin and Nelson, 1986; Wiese-Bjornstal and Dufek, 1991; Harman et al, 1992; Harman et al, 2000; Polcyn et al, 2002) and lower CoM of the body (Harman et al, 2000). An increase in step width and subsequent increase in hip abduction may be another factor in an effort to increase stability as greater load is carried. The increase in hip adduction occurs during the swing phase of gait, with load carriage resulting in the femur swinging closer to the midline of the body. It is worth noting again that none of the changes to peak abduction or adduction with load carriage were significant, only the effect on the RoM.

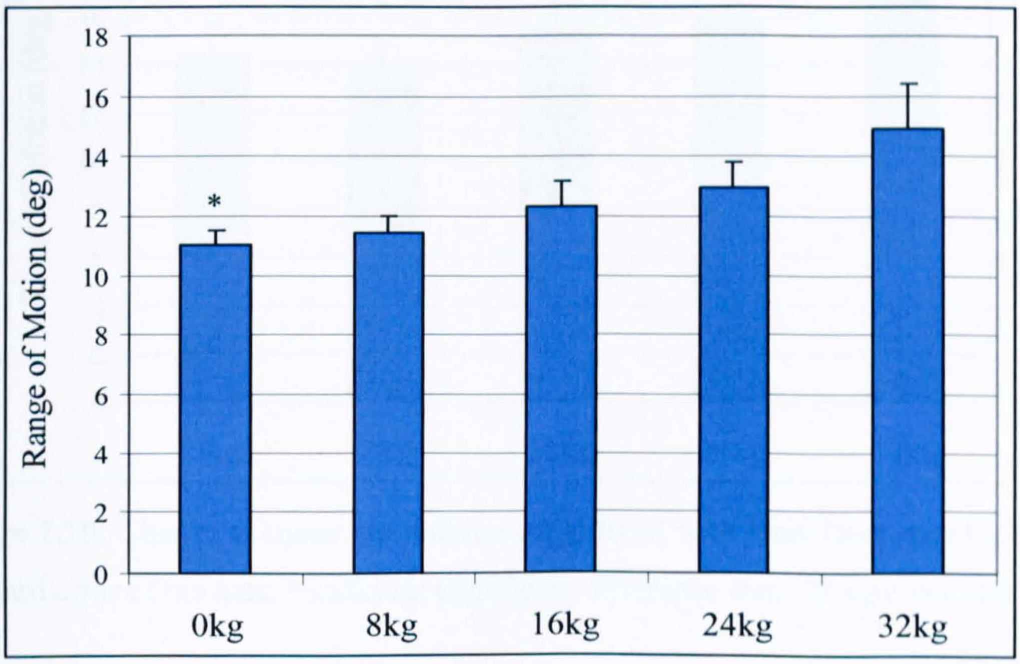


Figure 7.9: Change in mean frontal hip angle RoM with load, error bars represent standard error of the data. * indicates significant difference from 32 kg condition.

As well as an increase in hip abduction RoM with load a significant ($p<0.05$) difference was also observed with hip rotation (figure 7.10). An increase in load led to a greater RoM of the hip in the transverse plane. This was primarily as a result of a decrease in minimum hip rotation. Minimum hip rotation is equivalent to external hip rotation. This greater external hip rotation may be a result of the wider step width and hip abduction forcing the hip to rotate to accommodate these changes. The clinical significance of change in hip rotation is uncertain, with no comparative detailed data within the literature (Khamis and Yizhar, 2007).

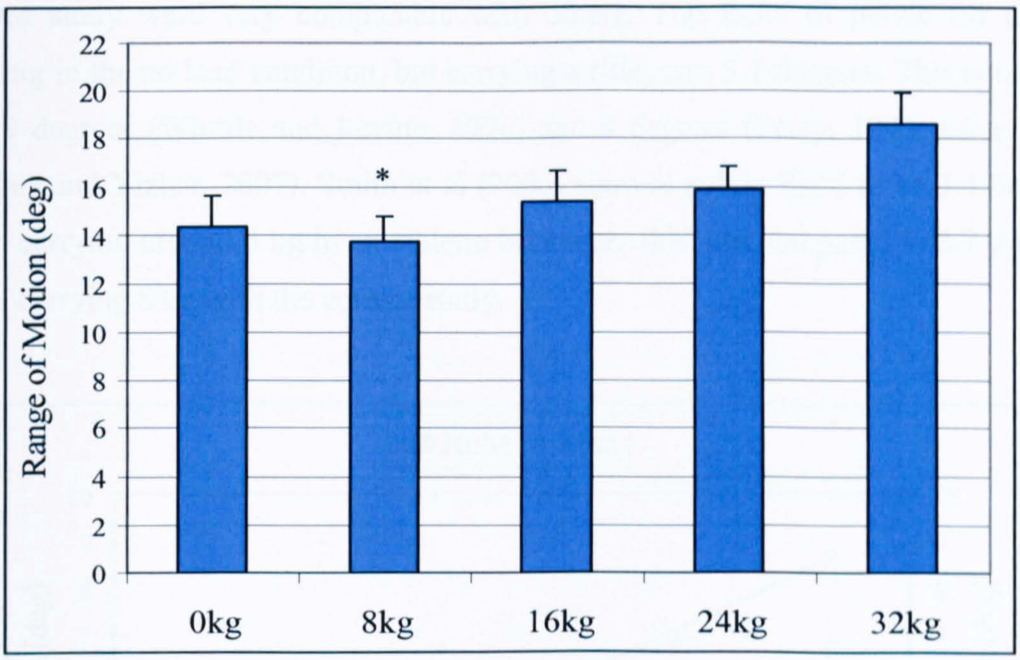


Figure 7.10: Change in mean hip rotation angle RoM with load, error bars represent standard error of the data. * indicates significant difference from 32 kg condition.

Pelvis Angle

The angle of the pelvis has again been the main concern of clinical gait analysis, with relatively few load carriage studies having examined changes to this angle. Pelvic tilt angles do not show large degrees of variation within the stride, as observed with other angles of the lower limb, as differences between the maximum and minimum values are often quite small. Pelvic tilt follows the same general trend of a trunk angle graph with one peak and trough per stride. Pelvic obliquity, as one may expect, has two peaks and troughs per stride. Changes to pelvic rotation are harder to categorise, generally the maximum rotation is observed at heel strike and minimum at toe-off. Pelvic rotation is not defined as internal or external, this is due to the fact it moves as one unit. Therefore rotation will either be to the left or right.

Results from this study showed a significant ($p<0.05$) increase in the RoM of the pelvis angle in the sagittal plane, this is more commonly referred to as pelvis tilt. The greater RoM of pelvis tilt was almost solely as a result of an increase in the maximum (or forward) pelvis tilt angle. This increase in maximum pelvis tilt was also significant when assessed with a MANOVA statistical test. Figure 7.11 shows the main effect of load on pelvis tilt RoM (histogram bars) and maximum angle (scatter plot and trend line). Reading the literature revealed the values for pelvic tilt with this current study were very comparable with others. The RoM of pelvic tilt during walking in the no load condition, but carrying a rifle, was 3.7 degrees. This compares to 2.9 degrees (Whittle and Levine, 1996) and 4 degrees (Perry, 1992; taken from Khamis and Yizhar, 2007). Smith et al (2006) showed pelvic RoM to be 3.4 degrees when carrying around 6 kg in an athletic backpack, this was compared to 3.7 degrees when carrying 8 kg with the current study.

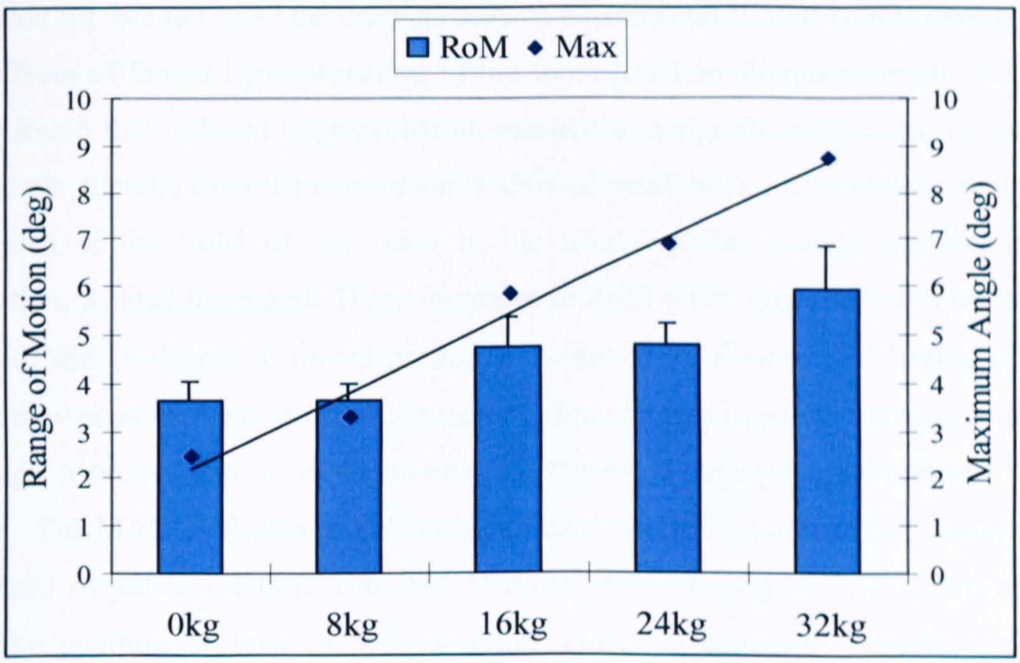


Figure 7.11: Histogram columns show change in mean pelvis tilt RoM with load, error bars represent standard error of the data. Scatter points and trend line show change in mean maximum pelvis tilt angle against load.

In the case of pelvis tilt the maximum angle is probably of more interest than the RoM; as is the same with the trunk angle. Figure 7.11 shows a comparatively linear relationship between maximum pelvis tilt and load, the greater the load the greater the tilt. Other studies have shown an increase in pelvis tilt with load carriage in a backpack. This has been shown in dynamic studies (Smith et al, 2006) and with static posture (Filaire et al, 2000). Smith et al (2006) assumed a positive relationship between pelvic tilt and forward lean. They suggest that the clinical implications of this are that greater forward lean of the trunk leads to increased lordosis. This can result in compression of the lumbar vertebral bodies and facet joints, increased interdiscal pressure and the narrowing of the intervertebral foramina which can result in chronic lumbar pain disorders (Smith et al, 2006). This current study also suggests a possible link between pelvis tilt and forward lean. Trunk angle is the principal kinematic parameter of interest due to its implications on overuse injuries of the lower back. When trunk angle cannot be measured, due to biomechanical equipment limitations or interference of the load carriage equipment with the C7 or shoulder, the tilt of the pelvis may be used to give an indication of forward lean.

Reviewing the literature revealed other studies that had researched the effect of pelvis tilt, but not in a load carriage setting. Khamis and Yizhar (2007) investigated the effects of forced hyperpronation of the foot on pelvic alignment while standing. They found that induced hyperpronation resulted in a significant increase in anterior pelvic tilt. Results from the current study showed small but consistent non-significant increases in the RoM of the ankle in the frontal plane, namely supination and pronation, as load increased. These increases in RoM were only small and not on the scale of the 10 degree of forced pronation examined by Khamis and Yizhar (2007). They may however be a contributing factor to the increase in pelvic tilt seen with load carriage. More research is needed to establish these and other potential effects.

The MANOVA also revealed a significant main effect of load for a decrease in the RoM of pelvic rotation with load carriage. However, figure 7.12 clearly shows that the addition of load as low as 8 kg induced a decrease in pelvic rotation. However, this decline was only significant between the rifle and 24 kg condition. These results suggest that it may be the carriage of a backpack that results in a decrease in pelvic rotation as an accumulative effect of increasing load is not seen. A decrease in pelvic rotation with load carriage has been observed in previous studies (LaFiandra et al, 2002 & 2003; Smith et al, 2006). A potential reason for the decrease in pelvic rotation with backpack carriage (figure 7.12), is the restriction of rearward arm swing observed with the carriage of different types of backpack (Harman et al, 2000). However, the 0 kg condition with the current study was actually a rifle condition. Results from chapter 6 show that rifle carriage already restricts natural arm swing. It would be of interest to see if rifle carriage itself resulted in a decrease in pelvic rotation from a no load and no rifle, control condition. This would clarify if restricted arm movements were the cause, or at least a contributing factor, to the observed decrease in pelvis rotation. Other factors may be of more importance than rifle carriage, these are explained below.

LaFiandra et al (2002) suggested that a decease in pelvic rotation with load carriage is an effort to minimise torque production in the upper body. They suggest that torque produced by the lower body can be transmitted to the upper body. Therefore, minimising this will lead to reduced rotational force which may contribute to the increase in lower back injuries reported with load carriage. LaFiandra et al (2002) also add that carrying a backpack leads to decreased stride length at higher walking speeds. An increase in pelvic rotation is the 'normal' response to decreased stride length when walking speed needs to be maintained. This pelvis rotation is actually reduced to minimise torque production; therefore, an increase in stride frequency is needed to maintain walking speed.

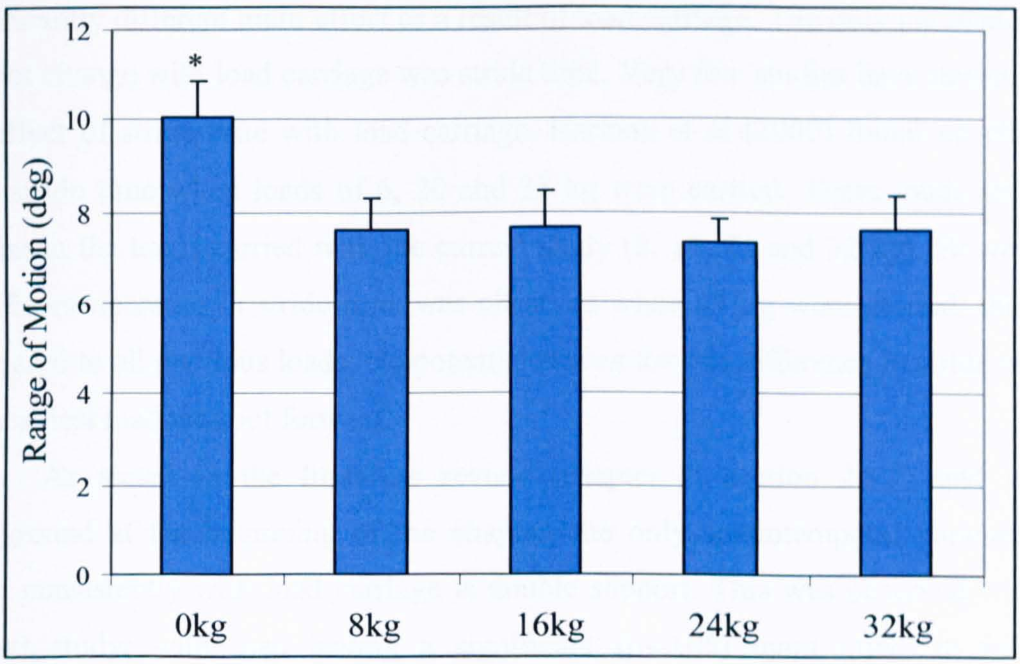


Figure 7.12: Change in mean pelvis rotation RoM with load, error bars represent standard error of the data. * indicates significant difference from 24 kg condition.

Results for pelvis rotation RoM gained with this study were very similar to results from Smith et al (2006). In the current study pelvis rotation was 10.08 degrees with no load, this decreased to 7.63 degrees when 8 kg were carried. This compares favourably with Smith et al (2006) who found RoM of 10.43 degrees with no load and 8.04 degrees with approximately 6 kg. Results from LaFiandra et al (2002) show mean values to be between 2 and 3 degrees less than the values stated above. However, the decrease in rotation between the backpack and no backpack condition is very similar to those found with the current study.

No differences were observed to the RoM of pelvic obliquity when loads of up to 32 kg were carried in a military backpack. Other load carriage studies have found changes with this parameter; however, this is with unilateral backpack load carriage. Studies have shown that carrying an athletics bag over one shoulder decreased pelvic obliquity in school children (Pascoe et al, 1997) and female college students (Smith et al, 2006). This change was mainly attributed to the asymmetric load carriage method adopted.

7.5.3 The Effect of Load on Spatiotemporal Parameters

Of the four stride parameters examined for this study, three showed a significantly different main effect as a result of load carriage. The only parameter that did not change with load carriage was stride time. Very few studies have investigated the effect of stride time with load carriage. Harman et al (2000) found no changes with stride time when loads of 6, 20 and 33 kg were carried. These loads are very similar to the loads carried with the current study (8, 16, 24 and 32 kg). However, a significant decrease in stride time was observed when 47 kg were carried, this was compared to all previous loads. No potential reason for this difference in stride time at the heaviest load was put forward.

As stated in the literature review (chapter 2, section 2.9.2) and in the background at the beginning of the chapter, the only spatiotemporal parameter to differ consistently with load carriage is double support. This was observed with the current study, with load having a significant ($p<0.05$) main effect to increase percentage double support. Figure 7.13 also shows the pairwise significant increase between the rifle, 8 and 16 kg condition compared to the 32 kg condition. This is consistent with the following literature (Ghori and Luckwill, 1985; Kinoshita, 1985; Martin and Nelson, 1986; Wiese-Bjornstal and Dufek, 1991; Harman et al, 1992; Harman et al, 2000; Polcyn et al, 2002). It is widely accepted that an increase in the period of double support with load carriage is directed at providing greater control and stability during walking. Polcyn et al (2002) also suggest that increasing the time spent with both feet in contact with the ground decreases the internal load on the joints of the lower extremity.

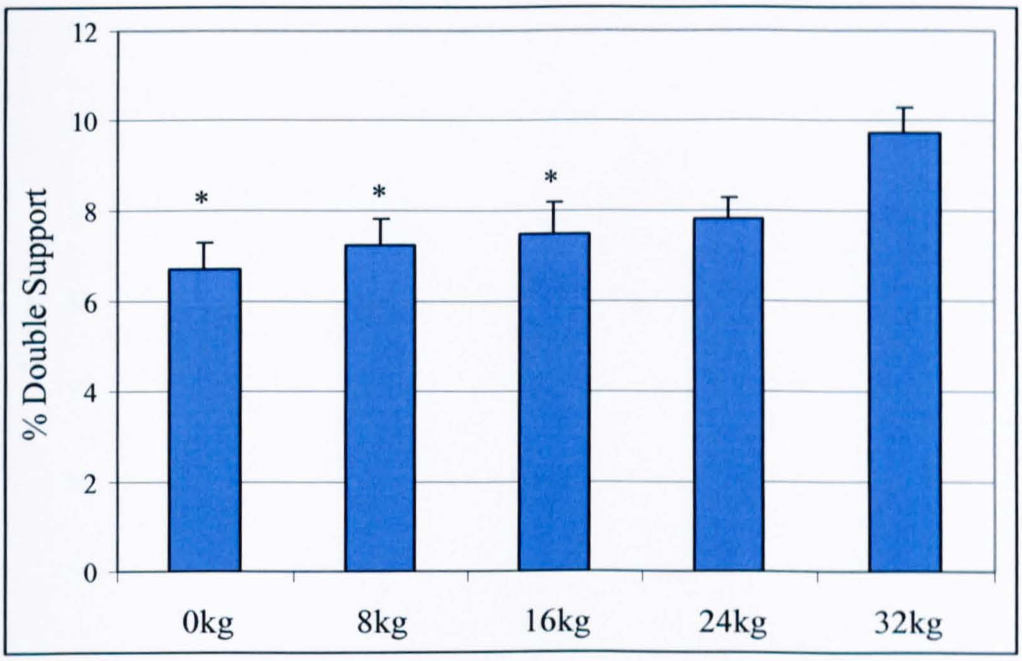


Figure 7.13: Change in mean percentage double support with load, error bars represent standard error of the data. * indicates significant difference from 32 kg condition.

This study also found a significant increase in percentage of the stride spent in the stance phase. This can be interpreted as a significant ($p<0.05$) decrease in percentage of time in swing. Figure 7.14 shows the significant main effect of load. Harman et al (1992) found a significant increase in % stance as load increased, as did Gory and Luckwill (1985). Martin and Nelson (1986) also found significant decreases in absolute swing time at heavier carried loads. Results from this study suggest that the increase in period of double support with load carriage is a function of the increase in single leg support. This increase in stance time will be present with both limbs, leading to greater overlapping of left and right foot single supports, thus resulting in greater double support. An increase in absolute stance time (not expressed as a proportion of the entire stride) with increasing load carriage has been consistently observed with studies from this thesis. Chapters 4 and 5 showed increase in single support with load. In addition Kinoshita (1985) reported a significant increase in stance time when carrying a load of 40% bodyweight in a backpack compared to a no load condition. There was also a trend for an increase at 20% bodyweight. A significant increase in stance time was also observed by Wiese-Bjornstal and Dufek (1991) when loads of 25 and 40% of bodyweight were carried in a backpack.

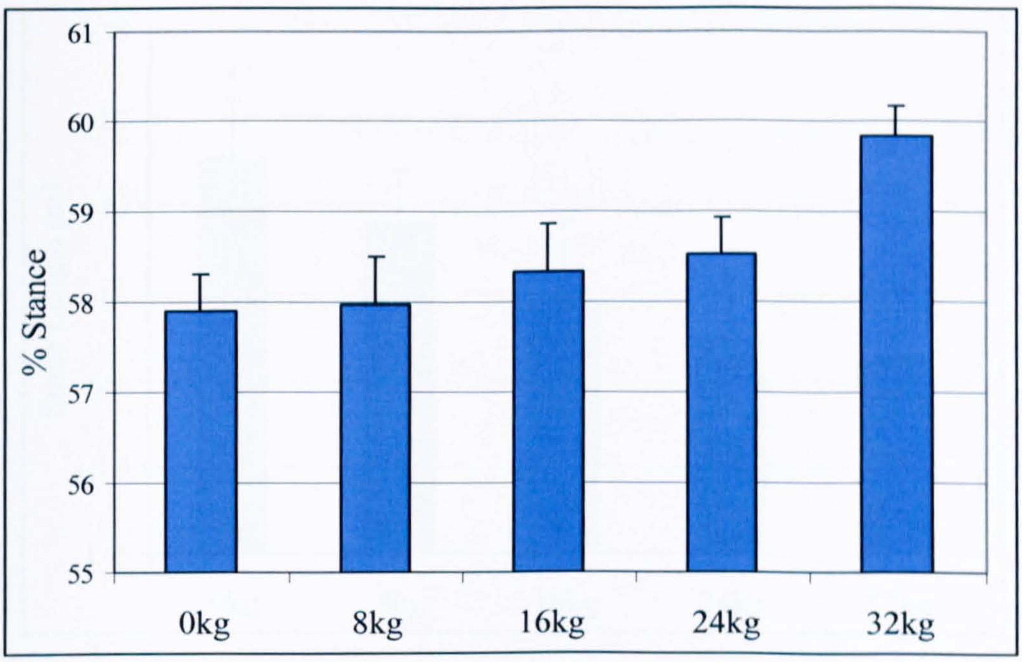


Figure 7.14: Change in mean percentage stance with load, error bars represent standard error of the data.

The final difference observed with load carriage in regard to the spatiotemporal parameters, was a significant ($p<0.05$) decrease with stride length with increasing carried load. Figure 7.15 shows the consistent decrease in stride length as load is added, the pairwise difference was only observed between the rifle and 24 kg conditions. Only studies by LaFiandra et al (2002 & 2003) and Vacheron et al (1999) found decreases with stride length with load carried by experienced backpackers. Results from Martin and Nelson (1986) showed a trend for a decrease. The exact reason for a decrease in stride length with load carriage is not clearly defined within the literature. Kinoshita (1985) hypothesised that stride length could be shortened in an effort to reduce the modification to gait patterns seen with load carriage. In other words return biomechanical parameters to more optimal no-load values. This may lessen the unnecessary stress placed on the body, particularly the metatarsal bones of the foot. LaFaindra et al (2002) suggest that the decreased stride length seen with load carriage may 'emerge as a consequence of the dynamics required to minimise torque production in the upper body.'

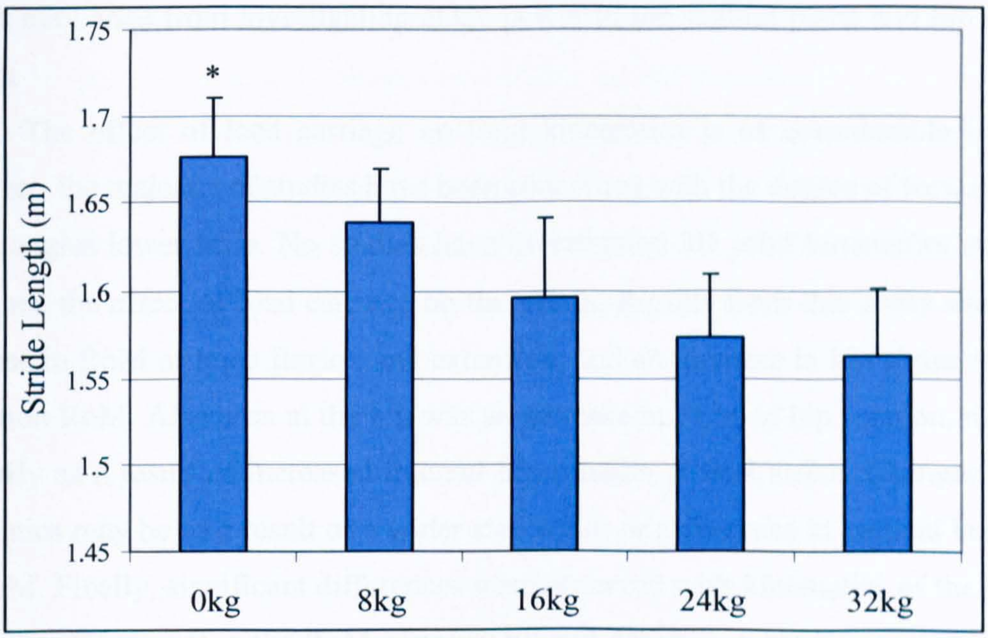


Figure 7.15: Change in mean stride length with load, error bars represent standard error of the data. * indicates significant difference from 24 kg condition.

7.6 Conclusions

This study utilised 3D bilateral gait analysis to investigate the effects of load carriage of up to 32 kg of human gait. During the study 3D lower limb joint kinetics and kinematics, as well as spatiotemporal parameters were measured.

All peak sagittal plane moments increased with load carriage, as observed in comparable studies in the available literature. However, the knee joint was found to bare a disproportionate share of the burden of increasing load. This compensation for load at the knee may increase the risk of developing overuse injuries at the knee joint. In the frontal plane all measured moments that moved the joint towards the midline of the body increased significantly as additional load was added. Changes to the rotational moments were of interest due to their possible link to acute and overuse injuries. Most important were the increase in all parameters measured at the knee, and increase in internal hip rotation moment. In all three planes the hip records the highest magnitude of peak and mean moments compared to the other joints. Joint power was measured and results presented; however, limited conclusions could be drawn due the lack of clear trends with the data and high inter and intra participant variations. Apart from the expected increase in mean joint powers with load carriage, interest for future studies may arise from investigating ankle power in the sagittal plane and hip rotator powers.

The effect of load carriage on joint kinematics is of considerable interest. However, the majority of studies have been concerned with the degree of forward lean or the angles lower limb. No studies have investigated 3D joint kinematics and few examined the effect of load carriage on the pelvis. Results from this study showed a decrease in RoM of knee flexion and extension, and an increase in hip abduction and adduction RoM. Also seen at the hip was an increase in RoM of hip rotation, this was primarily as a result of increased internal hip rotation at heel strike. Changes to hip kinematics may be as a result of a wider step width or a decrease in vertical height of the CoM. Finally, significant differences were observed with kinematics of the pelvis. A significant increase in the RoM of pelvic tilt and decrease in rotation were observed with increasing load carriage. Pelvic tilt may give an indication of forward lean, which is the principal load carriage kinematic parameter. The change in RoM of pelvic tilt was primarily due to an increase in maximum pelvic angle. This study showed the greater the carried load the greater the forward tilt of the pelvis. Also seen at the pelvis was a decrease in rotation as a backpack was added. This has been suggested to minimise torque production in the upper body which may contribute to the development of lower back injuries.

Numerous spatiotemporal parameters were measured, including stride length and time, and percentage of stride spent in double support and stance. These parameters have been subject to mixed reviews within the published literature with fixed verses free walking speed, and military verses civilian participants being cited for these differences. A universally observed difference seen with load carriage is an increase in double support. This was observed with this study and has been suggested to increase the stability while walking of the load carrier. Results also showed a decrease in stride length as loads increased. This has been reported before and is linked to a decrease in pelvic rotation. The percentage of the stride spent in stance increased (and subsequent decrease in swing phase), this again may be a mechanism aimed at increasing stability. Finally, no significant difference was observed with stride time.

To conclude, this study is relatively unique within the load carriage literature as it has conducted a 3D gait analysis of military load carriage. Results and subsequent discussion lead to the accepting of hypotheses 1, 2 and 3. Important results from joint kinetics and kinematics as well as spatiotemporal parameters were gained. Results have corroborated previous work where available and extended our current knowledge regarding military load carriage. Importantly to have been the initial investigation and benchmarking of previously unreported data. The main limitation with all biomechanical research is that it does not establish links between changes to observed gait and incidence of injury. This can only really be achieved by building on the biomechanical foundations and designing longitudinal or intervention studies around these results.

Chapter Eight – Military Load Carriage Injuries and Discomfort: Literature Review

8.1 Introduction

The title of this thesis is 'The biomechanics of military load carriage and injury potential'. So far the thesis has focused on the biomechanics of load carriage. The literature review and experimental chapters presented in the first half of the thesis have attempted to describe what happens to human gait during encumbered walking, and put forward potential links to injury development. The following chapters of the thesis present and evaluate data regarding the specific effects that load carriage has on injuries and discomfort. This chapter focuses on the literature regarding injuries in the military, and where possible alludes specifically to load carriage injuries. Chapters 9 through 11 describe the work conducted for this thesis during the collection of subjective load carriage injury and discomfort data from military personnel. However, in order to understand the role that load carriage has to play in the development of injuries, it is appropriate to review injuries in the military as a whole. This review will give background to experimental studies and also review the available, and suitable, methods for data collection.

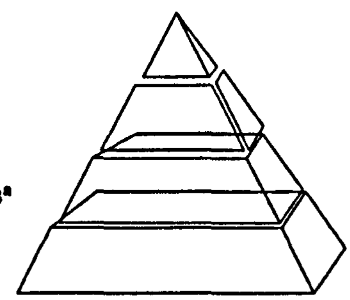
8.2 Military Load Carriage Injuries

8.2.1 Background

Injury rates in the military are of great interest to all involved, from regiment commanders to political decision makers, all the way down to the lowest ranked soldier. Injuries in the military have been termed a hidden epidemic (Jones and Hansen, 1996) and it is puzzling why it has taken so long for it to be considered an important issue. Major General Peake of the US army suggests that it is only now with the downsizing of military forces that has taken place over the last decade combined with an operational tempo that's up 300% from the cold war, and with the US army experiencing a recruiting shortfall of 6,000 in 1999, that every soldier must count. The lack of research into injuries in the military is in stark contrast to the efforts made in the 1940's with disease control (Peake, 2000). In January 1994 the Armed Forces Epidemiological Board, part of the US Department of Defence, formed the Injury Prevention and Control Work Group. Their single greatest accomplishment was the 'recognition that injuries are the leading health problem of the military services'. The group produced a technical report entitled 'Injuries in the military: A hidden epidemic'. The most important conclusions of the group were, (taken from Jones et al, 2000b):

- Injuries impose a greater ongoing negative impact on the health and readiness of U.S. Armed Forces than any other category of medical complaint during peacetime and combat.
- Training-related injuries treated on an outpatient basis cause a large amount of morbidity in military populations.
- Injury-related disabilities result in significant compensation costs.
- Databases reviewed are capable of identifying important types and causes of injuries.
- Valuable automated, linkable, military medical and personnel databases already exist, but are not optimally used for medical or injury surveillance.

More military personnel are killed, disabled or hospitalised due to injuries than any other cause. Only 2% of military deaths are due to combat-related injuries, the other 98% arise from unintentional injuries, illness, suicide and homicide (Smith et al, 2000). Songer and LaPorte (2000) suggest that 30 – 50% of disability cases may be due to injury, with lower back pain and knee conditions being the leading cause for lifetime compensation. Total direct costs of compensation paid to military personnel discharged from service reached $1.5 billion for the financial year of 1990, and in 1993 lifetime compensation costs of new disabilities was about $500 million. Hospitalisation due to injuries result in the largest direct costs of medical care, the most lost workdays and has the biggest impact on troop readiness for the military. Data from the 1st Gulf War suggest that musculoskeletal injuries accounted for 39% of all hospital admissions, compared with only 5% that were battle-related. Figure 8.1 is taken Jones et al (2000b) and shows the injury pyramid for the US services. It has been argued that reducing the number of injuries at the base of the pyramid will have a knock-on effect to the other layers, as these get more serious both in terms of personal and monetary cost to the military.



Injury Category	**Approximate Frequencies** **Army** n	**Navy/ Marine Corps** n	**Air Force** n
Deaths	**370**	**300**	**175**
Disabilities	**4,000**	**5,400**	**850**
Hospitalizations[a]	**21,500**	**11,300**	**9,400**
Outpatient[b]	**500,000**	– –	–

Figure 8.1: Injury pyramid for all US military services in 1994 (Jones et al, 2000b).

Many definitions exist as to what an injury is, or what is classified as an injury. Powell et al (2000) defined it as unintentional injuries, suicides and homicides. Injuries are not constant across all 3 of the services (Army, Navy and Air Force), a certain service may have a specific problem. Hospitalisation due to musculoskeletal injuries is more of a problem in the US Army and Marine Corps than the Navy and Air Force (20%, 21%, 17% and 14% of total hospitalisations respectively), Jones et al (2000a). This is more than likely to be due to the increased marching or running either with or without load for the land-based services. Other issues such as cultural differences, work load and training need also be considered. Subcategorising the Army further, specific units will have their own problems with ankle sprains a significant problem with paratroops.

8.2.2 Injuries to Female Members of the Military

Females soldiers are a group that are at an increased risk of injury. Review papers suggest that during basic training females are 1.5 – 2.0 times more likely to sustain an injury than their male counterparts (Jones and Knapik, 1999; Knapik et al, 2001). This phenomenon may be due to numerous reasons: Females have lower bone densities and consequently are less able to resist stress, their muscle mass is physiologically weaker and more readily fatigued (Jones et al, 1994). Bell et al (2000) investigated further into this matter and discovered that females were up to twice as likely to sustain an injury and at a 2.5 times greater risk of sustaining a serious injury. However, when considering physical fitness and not gender as the contributing factor to injury, the gender effect on injury was eliminated. The least physically fit individuals were at a 3.5 times greater risk of injury than the fittest individuals. The implication is that physical fitness, and not gender, is the major risk factor for the development of any injury (Jones and Knapik, 1999; Bell et al, 2000).

A review by Deuster et al (1997) reported that over 50% of female Army recruits attending 8 weeks of basic training reported an injury. Stress fracture rates were higher in females and these also represented a larger percentage of the musculoskeletal injuries that were sustained. More specifically pelvic stress fractures are a particular problem for females in the military. Pelvic stress fractures can occur when increased shear forces are exerted on the pubic rami by the hip abductors and the hamstrings (Kelly et al, 2000). Also, females have lower bone densities and consequently are less able to resist stress and their muscle mass is physiologically weaker and more readily fatigued (Jones et al, 1994). Significant problems are also associated with marching. Marching pace is usually set by the males. This puts females at an added disadvantage due to their shorter leg lengths, and therefore reduced preferred stride length. A study by Martin and Nelson (1986) showed that at a fixed walking speed, females have significantly shorter stride lengths and increased stride frequencies compared to males when carrying loads ranging from 0 to 36 kg. In order to maintain pace with the group, females will either increase their stride length or stride frequency, increasing the risk of pelvic stress fractures (Pope, 1999; Kelly et al, 2000).

8.2.3 Load Carriage Injury Data

Specific data for injuries caused as a direct effect of carrying loads is sparse within the available literature. Frequently it seems that load carriage has not been considered a risk factor for injuries, but more as an inevitable part of training and operations that cannot be modified. A comprehensive review conducted by Jones and Knapik (1999) highlighted many risk factors but neglected to include any load carriage variables. These may have included duration of load carriage, proportion of training involving load carriage, mass of load carried or modifications to load carriage systems (LCS). There are also insufficient intervention studies to compare these potential effects. Studies have been conducted to investigate the effects of gradually increasing training intensity and duration with new recruits (Popovich et al, 2000) and with Special Forces (Ross, 2002), and the subsequent effects on injury rates. Results showed that there were beneficial effects in reducing injury rates from this gradual increase in training. A similar study with graduated increases in load carriage duration and mass carried would be beneficial in enhancing our understanding of this area.

Load carriage research has tended to focus on the physiological costs of load as well as trying to improve performance tasks of a soldier (i.e. grenade throw, run times, shooting accuracy, obstacle course completion etc.). A number of studies exist covering these subjects (Bhambhani et al, 1997; Datta and Ramanathan, 1971; Harman et al, 1997; Kirk and Schneider, 1992; Lloyd and Cooke, 2000b; Quesada et al, 2000; Vacheron et al, 1999).

It is very difficult to predict long term injury patterns without the use of longitudinal studies; however some indicating (or risk) factors do exist. Repetitive loading of the foot has long been linked to overuse injuries (James et al, 1978; Cavanagh and Lafortune, 1980). More recently, this has been linked to vertical GRF and in particular impact forces (Nigg et al, 1987; Cavanagh and Lafortune, 1980; Keller et al, 1996). Increased impact force can be generated by increased running/walking speed (Keller et al, 1996; Hsiang and Chang, 2002), changes to stride length and stride frequency (independent to speed) (Martin and Marsh, 1992), and with an increase in carried load (Kinoshita, 1985; Harman et al, 2000; Lloyd and Cooke, 2000). A study investigating fatigue-related foot injuries suggests that high GRF coupled with localised fatigue increased the moments around the ankle and results in an increased likelihood of subtalar joint collapse, ankle sprains and stress fractures (Gefen, 2002). However, these studies mentioned above do not establish a dose-response relationship for the development of injuries.

There are clear links between increased impact forces or repetitive impact force and overuse injuries to musculoskeletal injuries of the lower extremities. It may be that loading rates will also be important in trying to predict long-term injury rates caused by load carriage. Other links between GRFs and injury may also exist, possibilities including a link between anteroposterior forces and the development of blisters (Knapik et al, 1996) and mediolateral forces and their effects on stability (therefore reducing potential breaks and strains caused by twisting or falling).

8.2.4 Epidemiological Studies

There are many epidemiological studies available investigating many different aspects of military injuries; these highlight the severity of the problem, potential risk factors and techniques for surveillance, (see Gardner et al, 1996; Canham-Chervak et al, 2001; Gruhn et al, 1999; Harwood et al, 1999; Heir and Eide, 1996a; Heir and Glomsaker, 1996b; Jones et al, 1993; Jordaan and Schwellnus, 1994; Linenger and West, 1992; Ross and Woodard, 1994; Smith and Cashman, 2002; Kaufman et al, 2000; Altarac et al, 2000; Lauder et al, 2000). The majority of the literature mentioned above originated in the US, although a small number of studies have been conducted in the UK and Scandinavia, with the risk factors derived from these.

In 1996 Jones and Hansen conducted a comprehensive review of injuries in the US military. To aid the future assessment and evaluation of military injuries they adapted a table entitled 'Five steps of the public health approach to injury prevention and control'. The attempt was to produce a systematic approach to tackling military injuries and adopt methods to measure their effectiveness. The five steps highlighted by Jones and Hansen (1996) were:

1. Determine the existence and size of the problem.
2. Identify the causes of the problem.
3. Determine what strategies and interventions work to prevent the problem.
4. Implement prevention strategies and programmes.
5. Continual surveillance and monitor/evaluate effectiveness of prevention efforts.

As mentioned previously research into injuries in the military is a relatively new area for research. For this reason the majority of research has focused on the first two points on the 5 step model, determining the size of the problem and identifying risk factors. The scale of the problem of injury in the military has now been established and termed a 'hidden epidemic'. The next step was to identify the risk factors for injury, these include:

- *Intrinsic Factors* – Age (older age for trainees, younger age for soldiers), race, gender, low cardiorespiratory endurance (slow run times), low muscle endurance, sedentary lifestyle, tobacco use, low levels of job activity. (Jones et al, 1993; Jones and Knapik, 1999).

- *Extrinsic Factors* – High running mileage, frequent marching and running (Jones et al, 1993; Jones and Knapik, 1999). A recommendation of this thesis is that load carriage variables be included as extrinsic risk factors.
- *Anatomical Variations* – Genu valgum, varum, recurvatum (knock knee, bow leg and back knee respectively), excessive Q-angle and unequal limb lengths, (Cowan et al, 1996).
- *Biomechanical Factors* – Back and hamstring flexibility, high and low foot arches, bone geometry, restricted ankle dorsiflexion and increased hind-foot inversion (Kaufman et al, 2000).

8.2.5 Sports Research

The field of sports research is relevant regarding injury assessment and possible causes of these injuries. Overuse injuries due to increased impact forces and high volumes of impacts caused by running have been extensively researched and intervention strategies have been implemented with varying results. A large body of literature exists regarding sport injuries. A summary of this literature follows.

Thacker et al (2001) produced a systematic review of literature regarding the prevention of shin splints in sport. The review found that there was little strong evidence to support the use of either shock-absorbent insoles, foam heel pads, heel cord stretching, alternative footwear or graduated running in reducing the occurrence of shin splint injuries. They suggested that this was mainly due to limited methodology and inconclusive results. However, the most encouraging evidence for effective prevention involves the use of shock-absorbing insoles. It was recommended that young male athletes use these orthoses inserts as they may reduce the occurrence of shin splints by absorbing shock transmitted up the tibia on impact, stabilising the subtalar joint and decreasing pronation.

Yeung and Yeung (2001) compiled a review looking at the effect of different intervention strategies and how these helped to prevent lower limb injuries in runners. Interventions were the effect of modification to the training schedule, stretching and the use of external support and footwear modification. Evidence is presented to suggest that limiting the exercise to 1 to 3 times a week for 15 to 30 minutes significantly reduces incidence of lower limb injuries. This is however only in novice or new exercise subscribers and not experienced runners. Inconclusive evidence was gained from reviewing stretching intervention data. Stretching regimes differed extensively and only one of the 5 studies reviewed by Yeung and Yeung (2001) found significant differences. Inconclusive evidence was again found regarding shock absorbing insoles, this is in support of the current literature review. The use of knee braces and corrective insoles for malalignment showed some positive results for decreasing the incidence of knee and foot injuries, however there are only a limited number of studies and more data is needed to confirm this affect.

A review of the epidemiological literature regarding running injuries was conducted by van Mechelen in 1992. Risk factors highlighted for running injuries were previous injury, lack of running experience, running to compete and excessive weekly running distance. Many other potential risk factors were identified but contradictory or scarce research findings make their association unclear. Van Mechelen suggests that the focus of sports injury prevention should centre on changes of behaviour by health education. A well recognised risk factor for running injury is previous injury. Complete rehabilitation and early recognition of symptoms are very important and can be regarded as 'determinants of correct behaviour'. For complete rehabilitation running must not be started too soon so as to prevent aggravating or worsening the injury. With early recognition of an overuse injury the runner can either reduce the volume/intensity or temporarily stop training while the injury clears. Training guidelines for novice runners will be very different to advice for experienced athletes. For novice athletes running frequency, intensity and total distance should be built up gradually; individuals should consider a personal training programme targeted towards their specific needs and ability. With experienced athletes the major risk factor for overuse injuries is excessive weekly distance, reducing this is generally not an option due to detraining. Mechelen (1992) suggest that the question 'How much is too much' can only be answered by trial and error. Increasing training intensity at the expense of distance does not affect aerobic fitness detrimentally; however, the relationship between intensity and injury remains unclear. Mechelen (1992) concludes that a health education programme should be aimed at changing running behaviour by reducing running distances and/or reducing participation in long distance runs such as half and full marathons.

Other reviews assess risk factors associated with sports injuries (Krivickas, 1997; Neely, 1998a and b; Murphy et al, 2002), and investigate the relationship between injury and risk-taking behaviour (Turner et al, 2004; Bell et al, 2000).

8.3 Injury Intervention Studies

Steps 3 and 4 on Jones and Hansen (1996) 'Five step model' are concerned with determining and implementing intervention strategies; this is in progress within military injury research. Below are highlighted a few studies below focusing on the methods and results.

8.3.1 Reduced Running

Jones et al (1993) investigated the effect of high or low running mileage on infantry trainees over an initial training cycle lasting 12 weeks. The study followed two companies who committed 40 minutes a day to either running or marching. The low running mileage company did more marching and completed a total of approximately 173 miles over the 12 weeks, while the high running mileage company did more running compared to marching and completed 198 miles. Results from the study show that the high running mileage group had a 30% greater risk of injury than the low running mileage. When this was normalised to cumulative incidence of injuries against cumulative running miles, the injury rates for both companies were essentially the same. This suggests that total distance run is the main predictor for injuries. Risk of injury is not the only factor to be taken into account when considering the costs and benefits of aerobic training, the increase in fitness is the desired benefit from this type training. In this present study the high running mileage company did not exhibit faster run times for a 2-mile run on their final physical training test, 12 weeks after the initial intervention. In fact their run times were slightly slower (but insignificant) than the low running mileage group. The reality that increased running mileage has no immediate effect on performance but detrimental effects on injury rates was also reported by Pollock et al (1977).

Sedentary individuals do not exhibit the same type of injuries as exercise subscribers (Pollock et al, 1977) or they occur at a lower rate (Blair et al, 1987). These researchers suggest that exercise itself is the main cause of training related injuries amongst the inactive or novice.

Pollock et al (1977) undertook a study looking at the effects of increasing either duration or frequency of exercise and their effect on injury rates and aerobic fitness. The study involved 20 weeks of intervention with fitness testing and medical questionnaires at the beginning and end of the study. Participants used were 87 male (willing) inmates considered to be a relatively healthy group of men, although they were sedentary. Results showed that increasing exercise duration from 0 to 15 minutes a day for 3 days a week at 85 – 95% maximum heart rate showed a 22% increase in injury incidence. Increasing the exercise duration from 30 to 45 minutes increased the injury rate from 24 to 54% with a minimal (0.6%) increase in VO_{2max} (table 8.1). The optimal duration of exercise was 30 mins per day as this showed a positive increase in aerobic fitness with only minimal increases in injury rates. Frequency of exercise showed a disproportionate increase in aerobic fitness compared to injury rates, with a frequency of 5 days per week showing a 325% increase in injuries corresponding to only a 35% increase in VO_{2max} (table 8.2).

Table 8.1: Data from Pollock et al (1977) showing the effects of duration of training on aerobic fitness and injury incidence, with frequency and intensity constant.

Duration (mins/day)	**No of Participants**	**Injury Incidence (%)**	**Change in VO_{2max} (%)**
Control (0)	18	0	-1.0
15	20	22	8.7
30	25	24	16.1
45	24	54	16.7

Table 8.2: Data from Pollock et al (1977) showing frequency of training with duration and intensity constant.

Frequency (days/week)	**No of Participants**	**Injury Incidence (%)**	**Change in VO_{2max} (%)**
Control (0)	13	0	-3.0
1	15	0	8.0
3	25	12	12.9
5	18	39	17.4

This study although conducted on untrained, civilian participants shows a very clear relationship between increased exercise duration and frequency on injury rates. Whether this is the case, or to a lesser extent, within the trained, active members of the military has not been established.

Exercise intensity (or running speed) is not as clearly linked to injury rates, with some reports suggesting a faster running speed indicating a greater risk of injury. Other reports, including Macera (1992), proposed that running intensity decreases as a significant risk factor when total running mileage is taken into account. She also suggests that 'among the modifiable risk factors studied, weekly distance is the strongest predictor of future injuries'.

8.3.2 Shock Absorbing Insoles

Stress fractures are a major problem within the military due to the large amount of running and marching completed. Some of this is completed carrying a backpack loaded with up to 60-70% of the soldier's bodyweight. Stress fractures cause the greatest loss of training days at the UK Commando Training Centre Royal Marines (CTCRM), where the training of Royal Marines Commandos is undertaken (Ross and Allsopp, 2002). Even relatively minor metatarsal stress fracture requires a minimum of 6 weeks to heal before serious training can be resumed, then there is the additional delay while the recruit regains his former fitness (Ross and Allsopp, 2002).

Windle et al (1999) investigated whether if placing shock absorbing insoles in boots attenuated peak pressures at the foot-boot interfaces, as this may reduce the stress transmitted through the tibia and reduce the incidence of stress fractures. They collected data from 11 participants (who were heel-toe foot strikers) at a marching speed of 4.8 $km.h^{-1}$ while carrying a 32 kg Bergen and running at 12.8 $km.h^{-1}$ with webbing weighing 10 kg. Four types of insoles were assessed along with a control (standard issue army boots). Results showed that all 4 of the insoles significantly attenuated peak pressures generated during heel strike and toe-off. The best performing insole was Sorbothane®, which reduced mean peak pressure at heel strike by 23% during marching compared to the control condition.

Cavanagh (1987) suggested that forces produced during heel strike lead to greater stress on the skeletal system than the forces produced during toe-off, and therefore are theoretically more likely to lead to stress related injuries. The authors acknowledge that their study had not tried to determine if insoles actually decrease injury rates, but only decrease pressure under laboratory conditions. Only 11 participants were analysed with each condition only consisting of 3 repeat trials at walking speed and 6 at running speed. Hamill and McNiven (2000) suggest that at least 10 trials are needed when measuring kinetic variables to form a reliable and stable mean.

Another study in 1985 was commissioned to see if issuing shock-absorbing insoles to every Marine Corps trainee reduced stress related lower limb injuries. A large randomised trial was conducted and although peak pressures were reduced, there was no reduction in the incidence of stress fractures (Gardner et al, 1988).

Whether or not the placement of shock absorbing insoles inside boots actually reduces stress fracture rates over the long term remains inconclusive. Cushioning insoles may have other benefits apart from reduced pressures, such as; increased perceived comfort levels, reduction in blistering or improved heat and sweat dissipation.

8.3.3 Changes to Basic Training Regimes

Popovich et al (2000) divided 1,357 male soldiers undertaking basic training at Fort Bliss, US, into 6 companies. Two companies were designated 'control' and continued with standard progressive training, the remaining 4 companies were termed 'cyclic training' with avoidance of running either during the 2nd, 3rd or 4th week of basic military training. A forth intervention group called 'increased running mileage' was originally included but these withdrew during week 4 due to 'early impression of high injury rates'. Total injury rates for all recruits during the 8 week basic military training were 535 clinic visits documented by 343 soldiers (25% of new recruits). A total of 1,927 days of training were lost with overuse injuries representing an average of 1.4 training days lost per participant. Results from this study showed that a rest from running in either the 2nd, 3rd or 4th week did not reduce the incidence of stress fractures or other injuries and that injury rates were more related to variables other than the actual intended intervention. Trends were seen between injury rates and marching. The companies with higher injury rates all averaged an increased frequency of marching (6 compared to 5 days a week) and higher total marching miles (98 compared to 94 miles per week) than the lower injury rate companies. Popovich and associates suggest 'a constant pattern of regular running and marching, allowing days of rest, may be less injury producing than intermittent schedules of high and low stresses from running and marching'. Problems with the study were acknowledged by the authors, the main one being that it had not been possible to maintain constant experimental design. Factors such as the instructor, frequency, intensity, duration and total running mileage were not consistent, thus the intended intervention, in this case rest from running, was not the only variable that differed between groups.

In 1998 the CTCRM commissioned a study to investigate the physical aspects of Commando training in response to persistently high injury and dropout rates (Fallowfield et al, 1998). The Fallowfield report highlighted some flaws in the design of the training syllabus, particularly with relation to physiological adaptations to the training programme. The main objections were that the course was felt to be submaximal for the development of fitness, endurance and strength and also that inadequate rest and recovery time was given. Importantly the commission thought that the allocation of time for improving aerobic fitness by running, increasing upper body strength and progressive load carriage was insufficient. Also, specific skills such as rope climbing were inadequately taught. Finally, very little stretching was encouraged with ballistic and high impact activities being introduced early on in the original programme. Following this report a restructuring of the training occurred and the Revised Common Recruit Syllabus (RCRS) was created. The training programme was made more progressive and also a gradual increase in the work to rest days was initiated. More running was implemented to improve aerobic fitness, regarded as the most important factor for Royal Marine recruits. Strength training, in the form of weight training and free weights, started earlier in the programme as adaptations from strength training take 2 to 3 months to develop. Finally one complete rest day a week was recommended to allow time for the training adaptations to occur, and the concept of active rest was introduced.

A total of 1,483 male participants joined under the existing scheme and 2,091 under the RCRS. The pass rates were identical for both schemes at 57%. The main purpose of the Fallowfield study was to examine the effects that a change to basic training would have on stress fractures. Of those joining under the original syllabus 105 (7.1%) of trainees suffered 109 stress fractures. This was compared to 80 (3.8%) trainees suffering 92 stress fractures who enrolled under the RCRS, representing a significant reduction in the RCRS group ($p<0.001$). The peak stress fracture rates occurred at the point of maximum training, in this case the Commando tests, with these occurring in week 29 of the original scheme and week 25 for the RCRS. In conclusion this study confirmed the hypotheses that 'the incidence of stress fractures is directly proportional to training load'.

8.3.4 Studies Involving Military Load Carriage

As mentioned before very few studies have been conducted and published that look at injuries caused due to load carriage. For this reason the next section of the report will focus on injury studies where load carriage has been involved. Even this area of the literature is sparse as many military related papers just term it as physical training or marching and do not specify if a load was carried.

Knapik et al (1992)

In 1992 Knapik and colleagues published a substantive investigation regarding injuries sustained while marching with a carried load. They suggest that armed with the knowledge of the most frequent injuries sustained during a strenuous march with load, medical units will be more adequately prepared to recognise, treat and even prevent these problems before they seriously affect combat readiness. The study protocol involved a 20 km road march conducted on paved roads (82%) and gravel paths (18%), with the majority of the march (75%) being conducted on relatively flat terrain. Injury data were collected passively when the soldier requested medical care either during or up to 12 days after the march. However, active surveillance was conducted post-march by examining soldiers' feet for blisters and other foot ailments. The total injury incidence for the march was 24%, or 79 of the 335 soldiers sustaining an injury. Of these 79 soldiers, 12 required medical attention for more than one injury. The most common injury sustained was blisters as suffered by 32 soldiers (9.6%), accounting for over a third of the total injuries endured. The second most common injury was back complaints with 16 cases (4.8%), followed by foot pain with 11 complaints (3.3%). Twelve soldiers could not complete the march, of these 6 attributed this to back strains. No one, however, withdrew from the march as a result of blisters. Despite this, blisters were still the top cause of limited duty days proceeding the march with 18 days.

In addition to the passive surveillance, the feet of 180 soldiers were actively assessed for foot injuries directly following the march. One or more foot blisters were seen on 124 of the soldiers (69% of the sample), 108 soldiers (60%) has one or more hot spots and foot contusions were observed on 39 soldiers (22%). Knapik et al also suggested that the incidences of some injuries such as blisters are greatly under-reported.

Knapik et al (1997a)

Another study by Knapik and colleagues was published in 1997 and focused on the effect of load mass and load distribution on soldier performance and injury. The paper investigated the effect of carrying 34, 48 or 61 kg in either a traditional backpack LCS (the US Army's ALICE pack) or an experimental double-pack. Numerous parameters were measured including: Synthetic work environment task (which encompassed memory, mathematical, visual and auditory monitoring tasks); marksmanship, grenade throw, physiological measures, march times, and finally of particular interest to this review, body part discomfort and foot blister incidence. Fifteen Special Forces soldiers completed 6 maximal effort, 20 km road marches. Each march was conducted on different days, separated by 3 to 4. Results from the study showed that as load increased march times increase. Faster march times were observed with the ALICE pack compared to the double-pack, this was attributed to soldiers reported preference and familiarity with the ALICE pack. When soldiers carried the experimental double-pack they reported greater discomfort in the neck, abdomen and hip regions. However, they reported less discomfort in the lower back region when carrying the heaviest (61 kg) load. This may be important because as already stated in this literature review, low back pain is one of the leading cause of compensation payments (Songer and LaPorte, 2000), and the most likely reason for non-completion of a marching exercise (Knapik et al, 1992). Potential reasons for the reduced lower back discomfort experienced in this study may be due to the more upright walking posture adopted when carrying load in a double-pack. Studies stating this and other biomechanical effects of load distribution can be viewed in chapter 2. Another interesting conclusion from this study was that carrying 61 kg in the double-pack reduced the incidence of blisters compared to 61 kg in the ALICE pack. This was attributed to the decrease in shearing force that acts on the foot when load is more evenly distributed around the trunk; see section 2.11 for further details.

Knapik et al (1997b)

Knapik and colleagues (1997) investigated possible effects that the use of antiperspirants on the foot before a 21 km, 6.5 hour road march had on foot blisters. They state that 'Moisture and frictional shearing forces seem to combine to increase the probability of blisters during physical activity'. Therefore it was hypothesised that using an antiperspirant would reduce blisters. A double-blind study was established with participants asked to apply either an antiperspirant or placebo preparation to their feet for 5 consecutive days before the march. There was a high non-compliance rate to the schedule, but for cadets using the preparations at least 3 times before the march the incidence of blisters was 21% for the antiperspirant group compared to 48% in the placebo group ($p<0.01$). Other significant differences were found: 45% of cadets reported that their feet did not sweat compared to 17% of those in the placebo group. A side effect of using the antiperspirant was that 57% of participants using the antiperspirant group reported skin irritation compared to only 6% in the placebo group. Knapik et al concluded that 'antiperspirants may be an effective way of reducing foot blisters during road marching if applied for at least 3 nights before the march'. However, skin irritation needs to be taken into account for future studies. A load of 33 kg was carried on the march in a backpack.

Reynolds et al (1999)

Reynolds et al (1999) looked at injuries and risk factors in a 100-mile infantry road march (5 consecutive days of 20-miles). Two hundred and eighteen male infantry soldiers carried 47 ± 5 kg in an ALICE pack and webbing on a 100-mile tactical road march, with injury data collected by two methods of passive surveillance. Firstly, physician's assistants recorded all injuries that were treated at fixed medical stations. Secondly, all available medical records that were available were screened up to 15 days after the march to identify any new injuries, or to follow up previous injuries. Results showed that 36% of soldiers reported an injury of any sort, with lower extremity (94%) and lower back (4%) being the most common. Blisters were reported by 47 (22%) of the soldiers and accounted for almost half of the total injuries, in addition to 20 days of limited duty. The remaining 14% of injuries sustained by the soldiers were dominated by musculoskeletal injuries. Foot pain was reported by 8% of study participants, and also represented the largest single cause of limited duty days up to 15 days after the march. The remaining 6% of injuries consisted of sprains and knee, back and hip pain. Some independent risk factors for blisters and other injuries were also highlighted – these were younger age and cigarette smoking. This study adopted passive surveillance techniques which may not give a true reflection of actual injury rates as not all injuries may be reported. Soldiers may be more reluctant to disclose an injury due to the fear of looking weaker to their peers and Commanding Officers. Also they may have past experience of treating minor injuries such as blisters and so do not feel the need to consult a medical professional. Conversely, among the civilian population self reporting can also lead to over-reporting of minor ailments.

8.4 Load Carriage Injuries

The following section will try to group types, causes, effects and prevention of load carriage injuries. This does not attempt to categorise ALL load carriage injuries but to highlight the important issues and a selection of potential causes. Also, many injuries are multifaceted with more than one injury occurring at any one time caused by any combination of issues. The list has been created for this chapter by reviewing the relevant literature, and not from one specific source. Injuries are grouped in either short, medium or long term and refer to the length of time for them to materialise.

8.4.1 Types of Load Carriage Injuries

Short Term ⟶ *Shoulder, neck and upper arm pathologies.* May include trapped nerves and blood supply to arm, numbness, skin irritations, general pain and aching due to straps and the forced forward head posture as a result of carrying the pack. Many of these are also symptoms for Rucksack Palsy.

Lower back pain. Caused by rubbing/banging of pack, or by increased stress on the musculoskeletal system from the induced forward lean, again general pain and aching.

Foot blisters. Hypothesised that these may be exacerbated by load carriage due to increased shearing forces between the foot-boot interface, may be related to increased GRF in the y axis.

Metatarsalgia. This is pain and swelling in the foot and may be mistaken for a stress fracture but symptoms disappear with rest.

Lower limb pathologies. Specifically foot, ankle, knee or hip pain. This is most probably caused by the actual process of running or marching although exacerbated by load carriage.

Traumatic or acute injuries. The carriage of a load may increase the likelihood of falls. Load also decreases a person's ability to readjust during a fall due to reduced stability and mobility. Load placement also effects stability and may be linked to increased force in the x axis of GRFs.

Medium Term ⟶ *Overuse injuries.* These include stress fractures (usually of the metatarsals or tibia), muscle strains or tears (either in the neck/trunk region or lower limb). These types of injuries are caused by repetitive micro traumas. Again these injuries may be exacerbated or aggravated by load carriage.

Rucksack Palsy. Shoulder straps of the LCS cause traction injury to brachial plexus (C5 and C6 nerve roots). Symptoms include numbness, paralysis, cramping and scapular winging.

Chronic pain. Persistent display of short term injuries which may lead to chronic pain and a longer term effect.

Long Term ⟶ *Arthritis.* Osteoarthritis can be caused by excessive enzyme release breaking down cartilage in response to mechanical stress (Ruddy et al, 2001). It can occur in the knee and spine and less frequently in the shoulder. Load carriage places additional stress on the musculoskeletal system, on top of the already high risk occupation that the military have.

Back pain. This can be severe and debilitating resulting in scoliosis, kyphosis, vertebrae or disc degradation and sciatica.

Joint degradation. Usually occurs in the knee or hip joints and can lead to the need for joint replacement.

8.4.2 Effects of Load Carriage Injuries

Injuries in general and specifically due to load carriage have many detrimental effects to the military. These include: decreased combat effectiveness and morale of an individual and/or unit; increased injury rates on operations and during training; higher drop out rates during basic training and reduced troop readiness. Injuries also represent the single largest contributor to lost working days and greatest expense in new and existing compensation settlements.

In the long term problems may arise with soldiers retiring from active or administrative duty at an earlier age. This contributes to the military losing its older, therefore usually higher ranked, more skilled and experienced soldiers. Compensation for disability discharge as mentioned at the beginning of the chapter represents a huge expenditure (US$1.5 billion in 1990) for the armed forces. One of the most important reasons why injuries in the military have become an area of focus is because of the ethical considerations. Being a member of the military, by its nature, is a hazardous occupation; therefore, minimising these hazards is essential for risk management within the defence force decision makers.

8.4.3 Causes and Prevention of Load Carriage Injuries

The causes of injuries specifically due to load carriage, as suggested by soldiers themselves (Chapter 9), are superficially straight forward: The loads are too heavy, equipment is poorly designed and task requirements are excessive. Load carriage is an inevitable and essential part of military life. Reducing the actual load carried is unlikely to happen as technological advancements will only serve to increase the load as more equipment is needed for communication, survival and increasing firepower (Knapik et al, 1996). Therefore, optimising the designing of LCS is perhaps the only viable option. This will however only serve to minimise or stabilise the effects of carrying very heavy loads. A more progressive training regime, in terms of load carried and duration of carriage may also be important in injury prevention. This may only reduce injury incidence during training; load carriage injuries while on operations is clearly more difficult to attenuate. Another approach may be to alter training regimes or entrance criteria into the military. Reviews have highlighted that strength, body composition, physical fitness and anthropometry are all determinants of load carriage ability (Haisman, 1988; Knapik et al, 1996).

Previous equipment designed for the UK armed forces back in 1990 (90 Pattern), has been generally well received by the troops (Jones, 2005); however it does have its faults. The 90 Pattern consists of waist webbing and a Bergen, as stand alone pieces of equipment they are more than adequate. When combined into a LCS they neither integrate well with each other nor with other necessary equipment (e.g. body armour). Integration of all items on the soldier is the most important factor when considering redesigning LCS. It must be a well integrated webbing and Bergen combination, satisfy soldier's functional and operational needs and also interface well with other equipment and transport needs (i.e. a systems approach is necessary).

Other factors that may lead to injury could be ill fitting packs, exacerbated by the correct size packs being unavailable (either long or short back Bergen's).

Distribution of load within the LCS is again important as loads placed close to the body's centre of mass are more efficient (in physiological terms). More specifically, a backpack with the centre of mass situated close to the back and higher in the pack is more efficient than low and away (Obusek et al, 1997). Load distribution and its effects on efficiency is subject to some discussion within the literature. It is clearly more efficient for load to be high and close when walking in the lab or on treadmills, but a load placed high in a pack may cause increased lateral moments. This may particularly be a problem when walking on a steep gradient or on unpredictable, rough terrain. Lateral moments will have less destabilising effects with a lower centre of mass of the pack. Finally, the suspension and damping characteristics of the backpacks interface with the carrier may also reduce injury risk or feelings of discomfort. Ren et al (2005) simulated load carriage gait and found that decreasing the suspension stiffness of the backpack led to important biomechanical advantages. Namely, a decrease in the vertical force acting on the torso, which in turn may reduce the risk of tissue and nerve damage under shoulder straps and hip belts. Also observed was a significant decrease in computed peak values of peak GRFs with the model.

Designers of new LCS must take into account human factors: A load placed high in a pack is more efficient physiologically, but ergonomically this may reduce stability on uneven ground, thus a trade off is needed. Age and experience may also determine the likelihood of sustaining a load carriage related injury; lower age is a risk factor for injury with trainees and higher age with seasoned soldiers. In addition a lack of education/knowledge of how to correctly pack or wear a LCS by the soldier may influence injury risk. Scientific research has shown beneficial ways that energy cost can be reduced by the correct packing of kit (Obusek et al, 1997). Bygrave et al (2004) showed that a tight fitting pack significantly effects lung function by restricting the chest. This decrease in lung function is in addition to the effect of carrying a 15 kg backpack. It is essential that this knowledge is conveyed to the soldiers either through training or education.

8.5 Subjective Ratings and Comfort During Load Carriage

Comfort ratings have been used extensively during ergonomic research, and are a valuable tool is assessing the effect of load carriage on comfort. One of the first studies to utilise body comfort zones was conducted by Corlett and Bishop in 1976.

They used body comfort zones in addition to overall comfort to assess changes in workspace design. As well as concluding that changes to the working environment can significantly increase comfort, they say that both regional and overall body comfort ratings provides a reliable and robust approach to subjective data collection (Corlett and Bishop, 1976). Martin (2001) adapted the above approach to measure shoulder comfort during load carriage, and used it to assess the potential differences as a result of changes in design features to military LCS. She looked at 4 zones of the shoulder and assessed these for comfort using a one-way 5 point ordinal comfort scale (table 8.3). Significant comfort differences were observed with the design changes implemented such as plastic inserts in the shoulder straps to more effectively dissipate pressure and the use of an AirMesh material that improves the thermoregulatory qualities. A considerable amount of validation work was conducted by Martin and the using of the 5 point comfort scale to assess comfort of the 4 shoulder regions which was found to be both reliable and valid (Martin, 2001).

Table 8.3: Scale used to rate comfort as devised by Martin (2001).

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

Other considerable research has been conducted using comfort rating and body zones by Legg and associates in 1997 and then again in 2003. They used the Body Part Discomfort (BPD) scale (figure 8.2) to try and establish preference for specific LCS designs based on comfort.

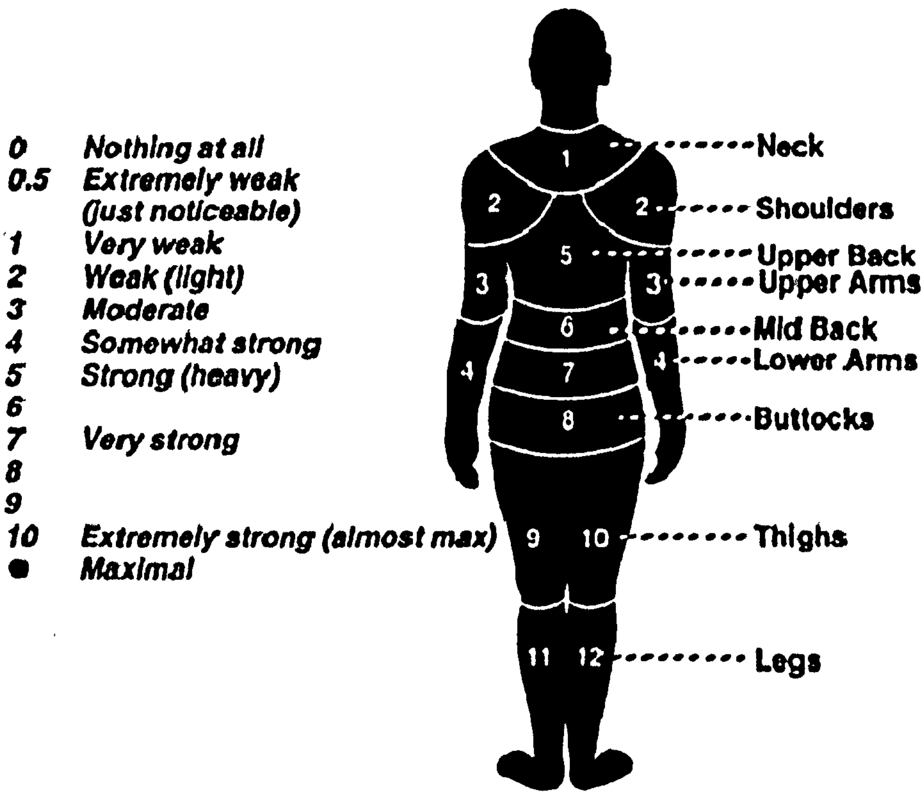


Figure 8.2: Body Part Discomfort scale as used by Legg and associates.

Results from the 1997 study showed that while different comfort rating were given for the pre-determined zones in figure 8.2, no significant differences were observed between the LCS. Reasons for this lack of significant difference may be due to the LCS being relatively similar with minor changes in design. Another factor may be that comfort measurements were taken after a 30 minute period of load carriage, this may induce a time error with ratings. Jones (2005) thought that although the BPD scale was very informative it would be too complicated to use in the field, as it could create health and safety issues due to the concentration required by participants whilst navigating a field course. To combat these issues of the complicated multi-zone ratings Jones (2005) collected subjective data using Martin's 5 point comfort scale (table 8.3) and asked military participants to rate comfort at the shoulders, back and hips. This subjective data were collected while participants completed a field course of mixed terrain while carrying 36.4 kg; the course took approximately 10 minutes to walk. Subjective results from the study showed that participants rated all 3 zones measured (shoulders, hip and back) more comfortable when carrying a prototype backpack (AirMesh LCS) compared to the standard '90 Pattern military LCS. Similar results were seen with a comparable field trial and laboratory based studies using the same scale was conducted using civilian participants (Jones, 2005).

Further load carriage research has been conducted in an effort to determine the effects of prolonged load carriage on comfort (Attwells, 2006). This work utilised the 5 point comfort scale (table 8.3) designed by Martin (2001); however, this time body comfort was assessed at 10 body zones. Shoulder, back and hip comfort were each broken down into 3 zones at region, and a tenth zone was placed at the thigh which was used as a control zone as little discomfort should be felt here. As well as these measures, 6 sites on the foot were measured for comfort. This totalled 16 body regions (figure 8.3).

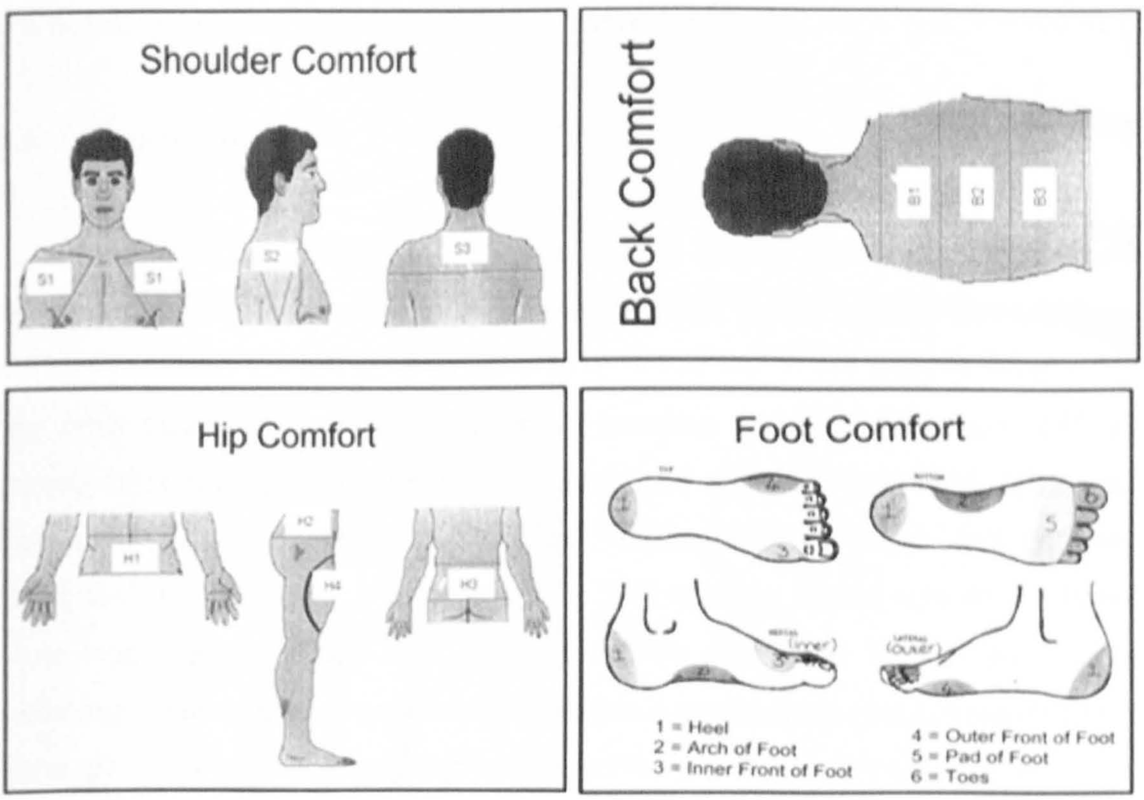


Figure 8.3: Body zones used to assess comfort during prolonged load carriage as used by Attwells (2006).

Comfort was assessed using the above method during two studies both on military participants. The first was a 2 hour forced-speed treadmill march carrying 20 kg, comfort data was taken every 15 minutes. The second was a 1 hour field march carrying between 20 and 25 kg, with comfort data being collected at the end of the march. Results from the laboratory trial showed that the foot was rated as the most uncomfortable region measured. However, comfort rating could not distinguish between the two LCS used, a double pack (AirMesh LCS) or standard military '90 Pattern LCS. The field study showed that the load baring regions of the body displayed the worst discomfort, namely the shoulder and feet (Attwells, 2006). Problems with the comfort zones used by Attwells (2006) (figure 8.3) were that the 3 regions of the shoulder, back and hips may be difficult to distinguish between especially during a load carriage trial. For example with zone S3 (figure 8.3) it is unclear if this is supposed to represent the neck, upper back or lower shoulders. A compromise between Jones (2005) and Attwells (2006) body zones may have given the most meaningful comfort zones. Comfort zones of the neck, shoulders, upper and lower back, hips and thigh may give a clearer effect of load carriage on discomfort whilst taking into account it's complexity during field trials.

8.6 Conclusions

Injury in the military has been termed 'A Hidden Epidemic' and it is now recognised that injuries are the leading health problem for the military services. More military personnel are killed, disabled or hospitalised due to non-combat injuries than any other cause. Injury is a multifactoral, complex problem, with many different aspects inter-relating, and therefore an integrated approach is needed. Many risk factors for injuries have been identified, although load carriage has not been recognised as one. Specific data regarding load carriage related injuries is limited. More studies/research into load carriage and its effects on injuries are needed, including intervention and experimental studies. Lessons from sports research can be learnt, particularly with respect to running and lower limb overuse injuries. Increasing both the weight and duration of load carriage has been shown to increase the subjective discomfort, measured by comfort rating scales, of military personnel. The analysis of GRFs may give an insight into injury prevention. Vertical forces have been linked to overuse injuries, particularly tibial stress fractures and knee joint problems. Anteroposterior forces may indicate increased likelihood of blisters and metatarsal stress fractures. Finally, mediolateral forces could be related to balance and stability, both influenced by the vertical and horizontal centre of mass of the load carriage system (LCS).

Chapter Nine – Initial Load Carriage Discomfort and Other Data Collected by Interviews and Questionnaires[5]

9.1 Introduction

Injuries to military personnel are recognised as the leading health problem for the military services. In recent years governments have also become more aware of their ethical responsibilities to better protect their soldiers from unnecessary risk of injury. These factors have led to military injury research being given higher priority and better funding. Early work focused on determining the existence and size of the problem, then the identification of potential risk factors. Now research is trying to establish implementation strategies and apply these where necessary. Due to the very sensitive nature of the military injury data, substantial barriers are present restricting the transfer of information. The viewing of military medical records or injury databases was not possible. Also, access to military personnel is difficult due to the increased number of operations the military are involved in and security issues. These factors combine to make the collection of injury data or the implementation of an intervention strategy almost impossible for someone outside of the military. For these reasons the focus of this thesis was discomfort during load carriage, and a retrospective look at load carriage injuries. The importance of understanding typical discomforts and most frequent injuries during load carriage and strenuous marching lies in the preparation and knowledge for medical units. Armed with this information they will be more adequately prepared to recognise, treat and even prevent these problems before they seriously affect combat readiness (Knapik et al, 1992).

This chapter details the initial undertaking of load carriage discomfort data collection by the subjective methods of interviews and questionnaires. As well as discomfort data, participants were questioned regarding their views on load carriage

[5] *Work from the following chapter published in Military Medicine, March 2007.*

systems (LCS), boots and other issues. Despite the inherent difficulties getting military personnel to take part in scientific trials, participants who took part in data collection for the current study were soldiers. The interview group were full time soldiers and questionnaire group were trainees.

The aims of the study were to determine the types, incidence and causes of any potential load carriage injuries or discomfort as a result of a forced-speed treadmill march with load. Also, to establish if these injuries or discomfort are typical of those while marching with loads outside of this trial, with this particular group of participants. Finally, to evaluate the effects these injuries or discomfort have on the soldiers. To achieve these aims two separate methodologies were adopted. The first utilised an interview and second a questionnaire, both were conducted following a prolonged period of load carriage. The two groups will be referred to throughout the chapter as the interview or questionnaire group of participants.

The same participants and protocol utilised for this study formed the basis of another study conducted by a colleague in the Load Carriage Research Group at Loughborough University. This study was concerned with the biomechanical effects of prolonged load carriage (Attwells, 2006). Although the two studies were completed simultaneously using the same participants, the comfort and cognitive data collected were analysed independently, except where stated, and separate conclusions drawn. The interview and questionnaire data were collected solely for this study.

9.2 Background

Injury rates in the military are of great interest to all involved from regiment commanders to political decision makers all the way down to the lowest ranked soldier. Injuries in the military have been termed a hidden epidemic and are now recognised as the leading health problem for the military services (Jones et al, 2000a). More military personnel are killed, disabled or hospitalised due to injuries than any other cause. Data from the first Gulf War suggests that musculoskeletal injuries accounted for 39% of all hospital admissions, compared with only 5% that were battle-related (Smith et al, 2000). Also, it has been suggested that between 30 – 50% of disability cases may be due to injury, with lower back pain and knee conditions being the leading cause for lifetime compensation (Songer and LaPorte, 2000). Despite these clear implications injuries caused as a direct result of carrying loads have not been researched to any great depth; instead research has focused on the effects of training and identifying risk factors for injury.

To assess the incidence and prevalence of load carriage related injuries many methods can be used, these include: questionnaires, focus groups, diary studies, literature searches, interviews, risk assessments and lab based studies. For the most complete analysis both qualitative and quantitative data should be collected. Qualitative data, as collected through interviews or focus groups are richer in detail and not as rigid in structure. Quantitative data, collected via questionnaires are a good way to evaluate issues within a large number of participants with minimal time restraints. For this study both qualitative and quantitative data were collected in the form of interviews and questionnaires respectively.

9.3 Methodology

9.3.1 Participants

Two separate groups of participants were used for the interview and questionnaire studies (table 9.1), with both groups completing the same protocol. Ethical approval was granted by Loughborough University under the generic load carriage protocol and effect of fatigue during load carriage protocol (G03/P18, R03/P98 respectively). Where needed, approval was granted by the MoD through the commanding officer of the Black Watch Regiment.

The interviews were conducted with 8 members of the 1st Regiment Black Watch at the Land Warfare Centre Battlegroup, Warminster, UK from the 2nd – 5th November 2004. All participants were full-time soldiers, but due to the military commitment of the UK in the Middle East soldiers present were of younger age with little operational experience.

The questionnaire was completed by 10 members of the East Midlands Universities Officer Training Corps (EMUOTC) between 17th – 31st March 2005 in the Load Carriage Lab in the James France Building at Loughborough University, UK. Nine participants were currently members of the EMUOTC and half having other military experience in the either Cadets or Territorial Army. One participant was previously a member of the Cadets but currently was not actively involved with the military. None of the participants were full-time soldiers with their average time involved with the military being 3 ½ years (± 2.2 years).

Table 9.1: Participant characteristics, standard deviation in parentheses.

	n	Age (years)	Height (cm)	Weight (kg)
Interview	8	19.1 (± 14.1)	174.8 (± 14.0)	66.0 (± 18.2)
Questionnaire	10	21.2 (± 1.4)	178.3 (± 3.7)	73.7 (± 6.3)

9.3.2 Protocol

Data were collected after participants completed a 2 hour force-speed (1.61 $m.s^{-1}$) treadmill march whilst carrying 20 kg. Load was carried in either a Standard Load Carriage System (LCS) consisting of a short back standard issue '90 Pattern Bergen and PLCE waist webbing, or using the AirMesh LCS which consisted of AirMesh Prototype III Bergen (which has functional hip belt and improved thermoregulatory qualities) and PLCE vest webbing. The standard LCS distributed load on the back and around the hips, whereas the AirMesh LCS is a form of double-pack with load on the anterior and posterior of the trunk. An unloaded SA80 assault rifle was also carried. Participants conducted the trial with both the standard and AirMesh LCS, the order of which was randomised. The interviews and questionnaires were completed after the second trial, which may have been with either the standard or AirMesh LCS. Every 15 minutes throughout the trial the participants were asked to rate the comfort of 10 body sites on the shoulders, back, hip and 6 sites on the foot (figure 9.1) using a 5-point comfort rating scale (table 9.2). An additional site was rated for comfort, this was at the thigh and was used as a control as little discomfort should be felt here. A simple cognitive test was conducted pre and post trial to establish any potential change in mental processing ability with prolonged load carriage.

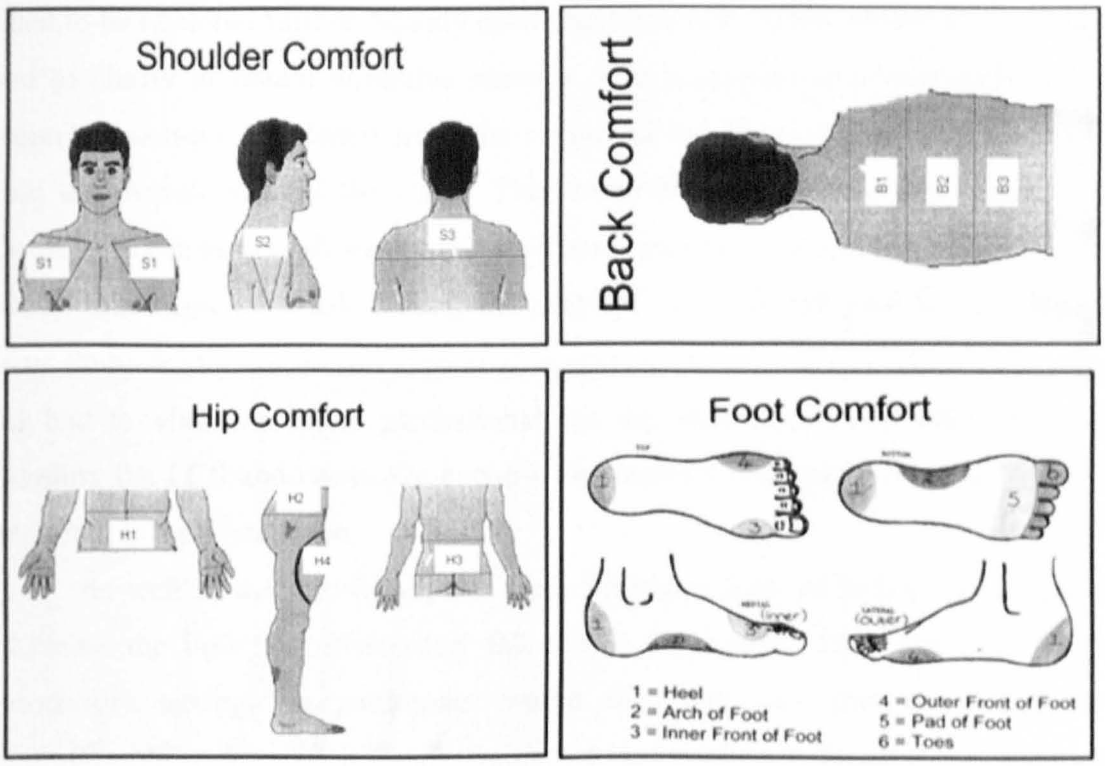


Figure 9.1: Zones of the body for which comfort was rated every 15 minutes, taken from Attwells (2006).

Table 9.2: Scale used to rate comfort.

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

9.3.3 Methods of Data Collection

As outlined in the Protocol two different methods were used to collect the subjective data, these are detailed below. Chapter 8, section 8.6 reviews the available literature regarding subjective data collection and section 3.8 of the methodology chapter refers to the chosen methods of data collection

Interview Study

A semi-structured interview technique was adopted. This used a small number of set questions, which directed the focus of questioning allowing interesting issues raised to be explored further. Mainly open questions were asked with closed questions used to clarify or obtain definitive answers. The interview focus was derived from research questions developed from the review of the literature and also bearing in mind the overall aims of the study. This initial list of questions were refined and piloted until the final draft was developed (see appendix 9.1 for a full list of questions asked). Questions included: During the trial did you feel any pain in the upper or lower limb; Is this discomfort typical of marching either with or without load; Have you had to visit a medical professional for this discomfort; and other questions regarding the LCS and boots. On average the interviews lasted 25 minutes and were conducted in a private room.

As well as the interviews, this study utilised a form of active surveillance to determine the injury or discomfort felt during the march. This was achieved by periodically asking the participant where they felt any discomfort and how uncomfortable they rated it, using figure 9.1 and table 9.2. Participants were also asked to discuss if the pain or discomfort they felt during the trial was typical of that while on military training exercises or operations.

To measure any potential decline in cognitive ability due to prolonged load carriage a simple cognitive test was completed pre and post trial (either after 2 hours or withdrawal whichever was sooner). This consisted of matching symbols to numbers in a restricted length of time (90 seconds); one point was awarded for each correct answer. Three practice cognitive tests were completed at a briefing session prior to testing to minimise any potential learning effect. Participants were randomly assigned 1 of 10 different cognitive tests, but never completed the same test more than once. See appendix 9.2 for a sample copy of the cognitive test.

Questionnaire Study

The questionnaire consisted of 27 questions, split into 7 main categories. These were: General questions, upper limb, lower limb, blisters, packs, boots and other. The questions were derived from previous work reviewing the literature and from the interview study conducted previously, also by reassessing the overall aims of the project. A first draft of the questionnaire was written, and then was edited by the project supervisor. This second draft was then piloted on members of the EMUOTC to ensure correct terminology and language was used for the military, also that the questions were easy to understand and answer. This final draft was then given to all

10 participants to complete in this study (see appendix 9.3). Questions 3b and 6b asked the participants to rate the comfort that they felt after the trial had ceased in the upper and lower limb, table 9.2 was again used to rate comfort. Non-parametric statistical tests were conducted on some of the appropriate questionnaire data to determine potential differences between responses given, significance was accepted at $p<0.05$.

Participants from both experimental groups (interview and questionnaire) were also asked to rate their comfort of key body zones every 15 minutes through the duration of the walking protocol. In addition participants were required to complete a simple cognitive tests pre and post trial. These data formed a key aspect of the concurrent study being conducted (Attwells, 2006). The comfort and cognitive data collected from the interview group of participants was analysed in agreement and independently for presentation in this chapter. The data were analysed in different ways to highlight the very different aims of the two studies. The comfort and cognitive data collected for the questionnaire study but was not analysed.

9.4 Results and Discussion

Due to the methodology adopted to acquire the data limited numerical results can be presented, particularly with the interview study. Limited results from the questionnaire study could have been presented separately, but no results from the interview. For convenience of presentation and to maintain continuity of the chapter the results will be presented followed by appropriate discussion. The following sections will discuss responses given by soldiers during the interviews, in addition to the mean comfort ratings and cognitive testing collected during the interview study. The section will also review and discuss the answers that were given by participants in the questionnaires. Appendix 9.4 shows the transcripts for the responses given by the participants during the interviews, their responses are grouped by each of the main categories of question. Appendix 9.5 shows a grid for the answers given to the questionnaire.

The interview was able to relate the current discomfort experienced as a result of the load carriage trial to the discomfort felt during training or operations by asking if the feeling was typical of that while carrying loads. This allowed the subjective data to be related to other situations when the soldiers would have to carry loads. As mentioned in the methodology 8 participants were interviewed following the trial, however only 4 of the participants actually completed both the Standard and AirMesh LCS trials, this was due to drop outs during the trial or injury forcing participants out of the repeat trial. However, all participants were interviewed even if they did not complete the 2 hours trial.

Results will be discussed according to the order they appeared in the questionnaire; upper limb, lower limb, blisters, LCS, boots and other. For an overview of types, effects and causes of load carriage injuries see Chapter 8, section 8.4. These data can only determine incidence of injury for this particular group of participants, who are of relatively young age with little operational experience. However, this may give an indication to the problems experienced by new recruits or trainees.

9.4.1 Answers to Questions Regarding the Upper Limb

Questionnaire Study

Question 3b asked whether or not the participant experienced any injury, pain or discomfort to the upper limb (this included the neck, shoulders, arms/hands and upper back). Nine out of the 10 participants said they did experience discomfort to some degree. The most common site for upper limb discomfort were the shoulders with all participants (who reported upper limb discomfort) rating them as slightly uncomfortable or above. The second most common site for discomfort was the neck with 5 of 9 participants stating it was 2 or above on the comfort scale, then the arms/hands and upper back had 2 complaints each. Figure 9.2 shows the most common sites for upper limb discomfort, with the shoulders being cited more frequently than any other region.

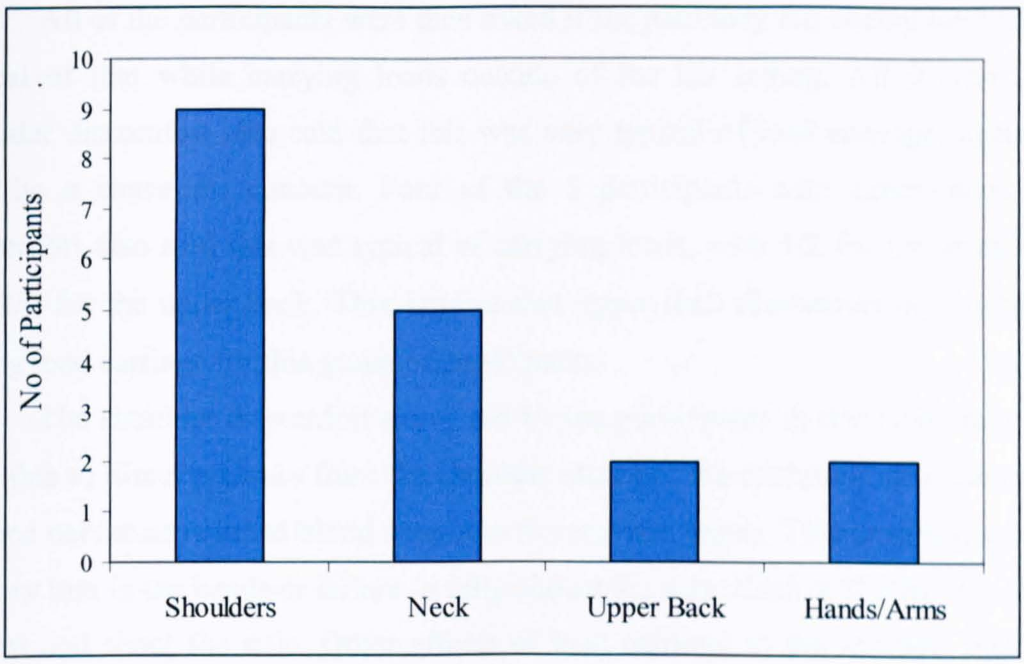


Figure 9.2: Most common sites for upper limb discomfort.

As well as being asked to locate discomfort the participants were also asked to rate the discomfort they felt using the scale in table 9.2. These ratings also showed that the shoulder was again an area for concern as the discomfort ratings were significantly ($p<0.05$) higher than any other region in the upper limb. Figure 9.3 shows a comparison of the discomfort ratings given.

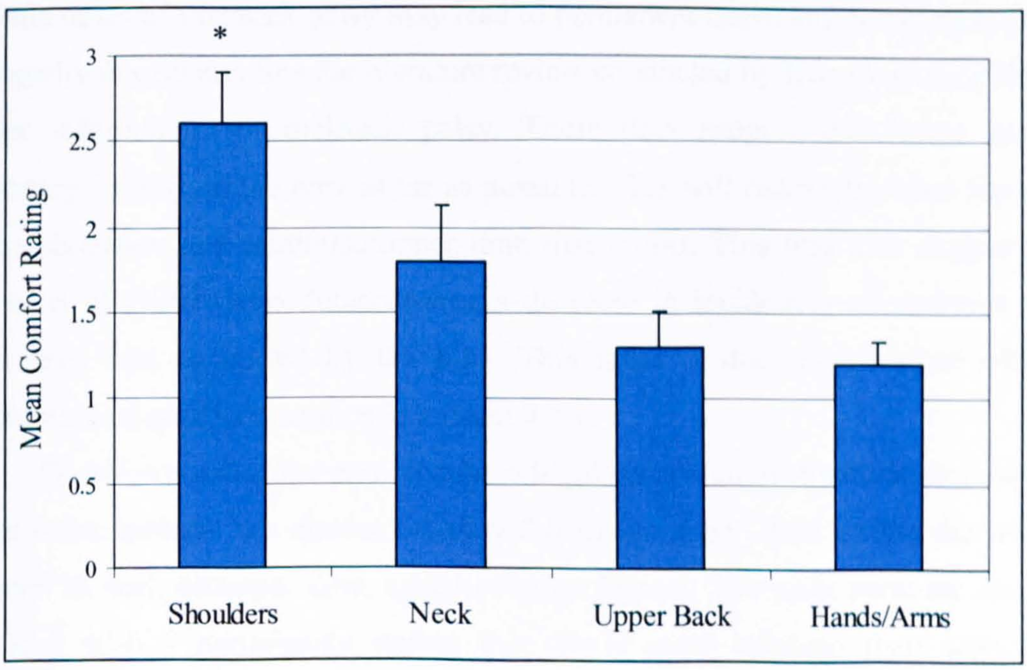


Figure 9.3: Mean comfort ratings for upper limb, error bars represent standard error. * denotes $p<0.05$.

All of the participants were then asked if the pain they felt during the trial was typical of that while carrying loads outside of the lab setting. All 9 who stated shoulder discomfort also said that this was very typical of load carriage; again this may be a cause for concern. Four of the 5 participants who experienced neck discomfort also said this was typical of carrying loads, with 1/2 for the arms/hands and 2/2 for the upper back. This implies that upper limb discomfort is very typical during load carriage for this group of participants.

The shoulder discomfort expressed by the participants in this study may have been due to direct pressure from the shoulder straps of the backpack, this can lead to trapped nerves or reduced blood supply to the arm and hands. This in turn may cause sensory loss in the hands or failure to fully abduct the arm which will affect the ability to aim and shoot the rifle. Other effects of load carriage to the shoulder and neck region are musculoskeletal pain due to the forced forward head posture or soft tissue damage and skin irritations caused by friction of the straps. The injuries mentioned above are mainly short-term injuries and symptoms will probably alleviate with time and rest from load carriage; a longer term effect may be Rucksack Palsy. Rucksack palsy is when the shoulder straps of the LCS cause a traction injury to the brachial plexus (C5 and C6 nerve roots). Symptoms may include numbness in the hands after the LCS has been removed, paralysis or cramping of the arm and scapular winging. Extreme cases of rucksack palsy may lead to permanent nerve and tissue damage and neuropathy may occur. See the literature review conducted by Knapik et al (2004) for further information on rucksack palsy. These data support the design goal of supporting LCS from the hips as far as possible. This will reduce the load supported by the shoulders and minimise upper limb discomfort. This was also suggested by Bessen et al (1987) who demonstrated a decrease in incidences of rucksack palsy when load was supported by the hips. This issue is discussed further with the presentation of additional results in section 9.4.4.

Question 4 asked the participants to highlight which of the following they feel would most increase the discomfort they felt in the upper limb during the trial: an increase in load, distance, time, speed or other factors. The most common response was load with 7 participants stating this would most heighten their feelings of discomfort. Second was distance with 6 responses, both speed and time were third with 5. Three of the participants thought that all of the factors would increase discomfort with one also adding terrain type or gradient. All options received a comparatively even response and goes to highlight the multifaceted problems and inevitable discomfort caused by load carriage.

The final question asked in this section was: 'After the load has been removed how long does it take for the discomfort to disappear?' Answers ranged from straight away to 24 hours. The most frequent response was 0 – 30 minutes, as given by 4 of the participants. As many different answers were given to this question responses were grouped into two categories, less than or greater than 1 hour. Six of the 10 participants stated that the discomfort in the upper limb due to carrying load diminished in less than an hour with the remainder greater than an hour. Although this discomfort dissipated fairly rapidly the time immediately after the doffing of a LCS may be a time in which a soldier is engaged in combat or needs to be operating at full effectiveness.

Within the literature focus on the upper limb is generally consigned to just discomfort and not injury. There are very few upper limb injuries reported or measured within the available literature. Reynolds et al (1999) suggested that 94% of injuries reported following 5 consecutive days of 20-mile road marches were to the lower limb and 4% involved the back. No injuries were reported relating to the upper limb. Very similar results were seen with a study by Knapik et al (1992), with no reported upper limb injuries. These two studies recorded injuries reported to medical professionals by soldiers and did not measure discomfort. In general, injury to the lower limb and back are recognised as more important health issues, with days of limited duty and long term disability more prevalent with these regions. However, these injuries are not specifically caused by load carriage and can be as a result of marching, physical training or other activities such as sports. Discomfort and potential injury to the upper limb is load carriage specific and although it does not have the ramifications that other injuries do in terms of monetary cost to the defence services the implications are still very real.

The principal importance of studying load carriage, and in particular the discomfort and injury caused, is that during military operations a period of load carriage will often result in a soldier being engaged in combat or needing to be operating at full effectiveness. A lower limb injury may stop soldiers going on operations, but load carriage injuries (like those mentioned above) may endanger a soldier or unit when an operation is active. Sole and Goldman in 1969 reported that soldiers were reaching the battle arena 'too exhausted to fight'. This highlights the importance of research focusing on load carriage and soldier mobility.

Interview Study

Upper limb pain was again a major issue with shoulder and neck pain being the major contributors to discomfort. By the end of the trial all of the participants questioned rated shoulder pain in one or more of the 3 regions (figure 9.1) as uncomfortable, with 4 from 8 participants saying shoulder pain was extremely uncomfortable, or 5 out of 5 on the comfort scale. Two participants that could not finish the 2 hour trial attributed their non-completion to shoulder and neck pain. All of the participants commented that the uncomfortable feeling in the shoulders while carrying loads was very typical. During the interviews participants revealed that shoulder pain due to carrying loads tends to disappear ½ to 3 hours following the removal of the load. This is very similar to the response given in the questionnaire study.

During the interviews after the completion of the trial many participants spoke freely about issues relating to upper limb discomfort during load carriage. Participant 8 believed the pain he felt between his shoulder blades while carrying the '90 Pattern LCS was due to the forced contraction of the upper back muscles to keep the load closer to his body. Another problem noted by a few participants was the cutting in of the vest webbing around the neck. This caused very severe skin soreness and inflammation; one participant was forced to withdraw as this pain was too great. Participant 3 remarked that carrying loads caused occasional back pain and believed this to be due to poor load distribution either in the Bergen or webbing. Participant 9 withdrew from both the standard and AirMesh LCS trial with shoulder and neck pain rating 5+. This left him in severe pain and was a result of a previous injury sustained before joining the Army. Load carriage considerably worsened the shoulder discomfort he felt, this was very typical and only occurs when he carries a backpack. He noted that the pain also persists for quite awhile after the removal of the pack. Participant 9 also said that he had visited both the onsite military doctor and his General Practitioner regarding this injury. The military doctor said nothing was wrong with the shoulder joint and a course of treatment was established which involved rest from load carriage. His pain still persists whenever he has to carry loads and this is making him seriously contemplate leaving the army.

Figure 9.4 shows the mean shoulder discomfort rating over time for all of the participants who took part in the trial. Each line represents data from both standard and AirMesh LCS combined. This graph shows a steady increase in shoulder discomfort up until around 75 minutes of the 120 minute trial. After this there is a drop in comfort ratings and then a less steep increase. The drop in ratings seen was a result of those participants who were experiencing the most severe shoulder pain dropping out from the trial, therefore their data is not represented from after they withdrew. Figure 9.4 also shows mean shoulder data for those who completed both the standard and AirMesh LCS trials. These participants show a much slower rate of increasing shoulder discomfort. However, a steady increase with time is still observed until the last 15 minutes of the trial where a slight plateau is observed. Both lines show an almost instantaneous increase in shoulder discomfort as the trial begins.

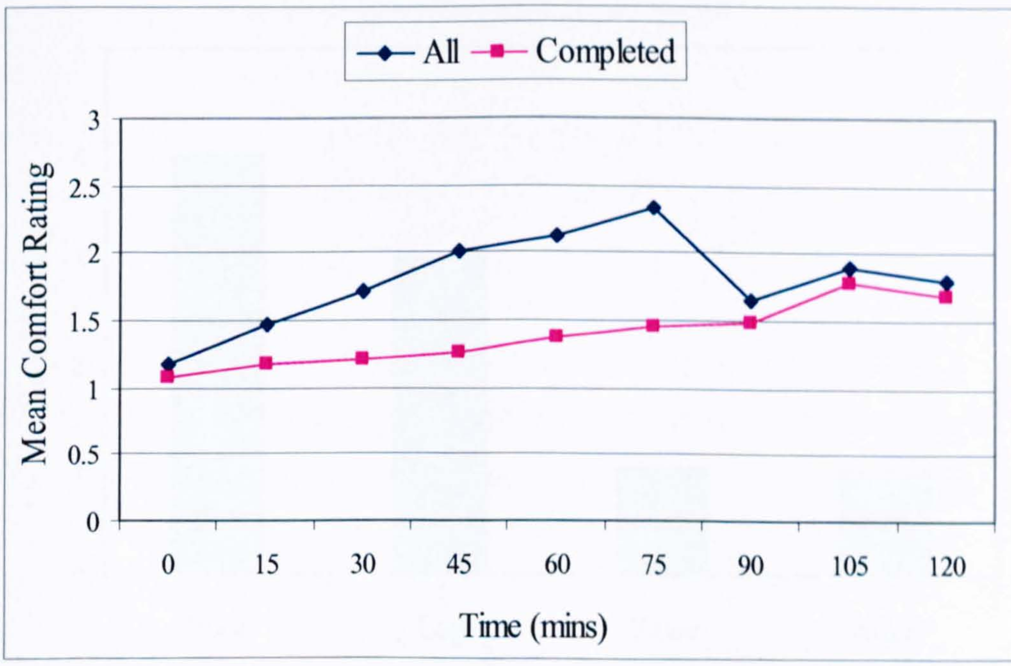


Figure 9.4: Change in mean shoulder discomfort over time for all participants and those who completed the trial from the interview group.

9.4.2 Answers to Questions Regarding the Lower Limb

Questionnaire Study

Fewer participants reported discomfort in the lower limb compared to the upper limb, 6 out of 10 compared to 9 with the upper limb. The majority of these being mild discomforts. The most common site for reported discomfort was the foot with 4 complaints, then the leg with 3 and finally both the knee and ankle accounting for 1 case each (figure 9.5). Although efforts were made to distinguish between blisters and actual foot pain (i.e. pain in the arch of foot, metatarsalgia and other musculoskeletal problems), it is unfortunately not possible to be sure that the foot pain stated by 4 participants was an actual musculoskeletal disorder and not just blistering. The cases of discomfort in the leg and foot were all stated as being typical of that while marching with loads. However, this is not the case with the knee and ankle as these were not typical discomforts felt while marching and may be due to walking at a fixed speed on a treadmill. Other studies have shown differences in maximum ankle and knee angles in males with treadmill compared to over-ground walking (Alton et al, 1998), this may account for the discomfort felt here.

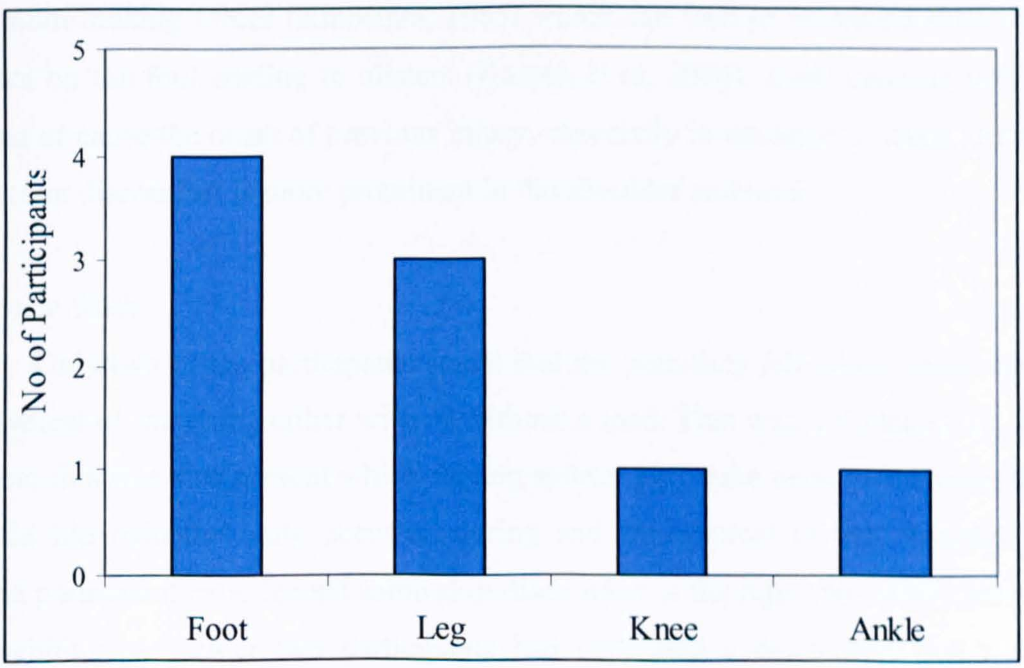


Figure 9.5: Most common sites for lower limb discomfort.

The average comfort rating given by the four participants who stated discomfort in the foot was 3 or uncomfortable. This is very similar to the comfort ratings given when the participants were asked about blisters, and may be another indication that blisters and foot pain were not distinguished between properly. All 3 participants who reported leg pain rated it as 2 or slightly uncomfortable, this is a fairly low score and may equate to an aching muscle or very slight tendonitis. The comfort ratings for the participants who reported the knee and ankle pain were 2 and 3 respectively. Only 1 participant said that the pain they felt during the trial was similar to that while undertaking un-military related activities and this was a slightly uncomfortable pain in the foot that occurred while playing hockey.

These findings suggest that lower limb injury or discomfort may not represent a substantial problem in the short term; however, it is a greater concern when looking towards the medium and longer term with tendonitis, joint degradation and particularly stress fractures of the tibia and metatarsals being a major cause of injury and disability. Increased vertical impact forces at heel strike during walking and running are a risk factor for the development of overuse injuries (Cavanagh and Lafortune, 1980; Nigg et al, 1987; Keller et al, 1996). The forces generated can be increased by a number of factors including load carriage (Kinoshita, 1985; Harman et al, 2000; Lloyd and Cooke, 2000; Polcyn et al, 2002). Load carriage also increases the maximum braking forces (Kinoshita, 1985) which can lead to increased sheer forces that act on the foot leading to blisters (Knapik et al, 2004). Load carriage may also worsen or cause the onset of previous injury, especially in the knee or ankle. Acute or short term discomfort is more prominent in the shoulder and neck.

Interview Study

Only two of the participants stated that the pain they felt while doing the trial was typical of marching either with or without a load. This was a skeletal pain in the heel but this was also present while playing sports. The same person also complained of mild hip pain that only occurred during and was typical of load carriage. The second participant experienced some skin discomfort at the hips caused by rubbing of the webbing. A further two participants had expressed a discomfort that was not typical of marching with loads, these were mild foot and ankle joint pain; again this may have been due to the forced speed of the treadmill. Three of the participants mentioned that they had knee pain while partaking in sports and one ankle pain. Marching and load carriage also induced this same feeling, but were not the causes of the injury.

Results from the interviews suggest that lower limb injury or discomfort did not represent a substantial problem, especially within this sample group, after a 2 hour treadmill march with 20 kg. Any pain or discomfort was only mild and was not stated as restricting their ability. This is supported with the subjective data collected showing only one participant rating discomfort in the thigh (or control) as greater than 1.

9.4.3 Answers to Questions Regarding Blisters

Questionnaire Study

Blisters were experienced by 6 out of 10 of the participants during the trial. Of these 5 said that this was typical of marching either with or without a load. From the other 4 that did not get blisters 2 said that this was not typical of marching, indicating that they do usually get blisters. Although this may seem high, other studies have found similar numbers to be affected. Knapik et al (1992) reported that 69% of soldiers experienced blisters after a 20 km road march. Knapik and colleagues again in 1997 found 45% of soldiers having blisters after a 21 km road march. Both these studies used active surveillance to determine blister rates. Reynolds et al (1999) used passive surveillance to determine injury rates during 5 consecutive days of 20-mile road marching. Blisters were the number one cause of injury with 22% of soldiers taking part in the exercise experiencing them, this accounted for 48% of the total number of injuries. Foot blisters are the most common load carriage related injury (Knapik et al, 1992 & 1997a; Reynolds et al, 1999). Load carriage has also been shown to increase blister incidence independently to other factors (Knapik et al, 1993; Reynolds et al, 1990). The most common place that blisters occurred during the current trial was on the heel (8/13), then the balls of the feet (3/13) and finally the toes (2/13), figure 9.6. Foot blisters may represent a minor inconvenience to you or me but are a larger problem within the military. Knapik et al (1997b) state that 'Foot blisters can considerably reduce locomotion, impair concentration and affect the soldier's ability to respond to emergencies.' Also a broken blister can become infected due to limited sanitation out in the field.

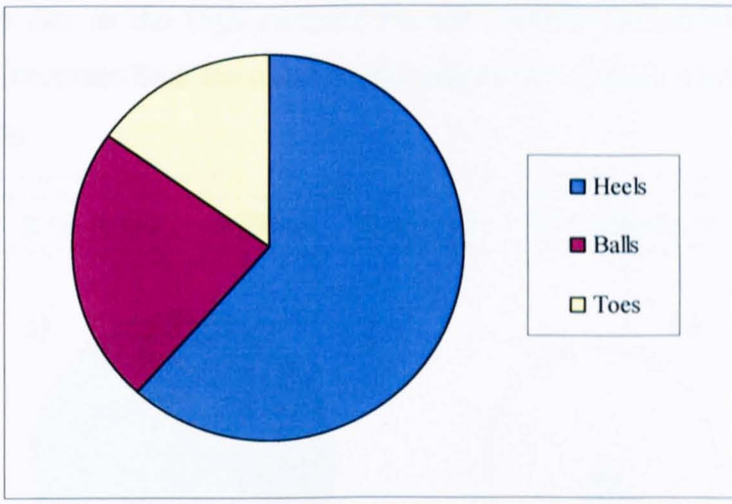


Figure 9.6: Most common sites for blister formation on the foot during the trial.

According to the participants questioned blisters generally took between 1 and 3 days to disappear, as stated by 6 of the participants. The remaining 4 participants were equally split between blisters usually disappearing in under a day or over 3 days. Blisters can be treated either by visiting a clinic that treats blisters and other foot ailments or by previous blister experience. The latter is termed self-manageable. All but 2 of the participants thought that blisters were self-manageable and did not require a visit to a clinic or medical professional, the remainder took no action at all. As well as the formation of blisters the participants were also asked about hot spots. Hot sports are areas of increased heat or friction that occur at the points where the feet (or boots) contact the ground. Six participants experienced hot spots during the trial; these were not necessarily the same 6 that experienced blisters. Seven of the participants stated that they would usually get hot spots while marching either with or without load. Hot spots are not debilitating like blisters can be, but cause extra discomfort. Whether or not hot spots are 'pre-blisters' or a separate entity is up for debate within the literature. The participants were then asked what they feel would increase the discomfort caused by blisters or hot spots. There was a fairly even response with time and distance receiving 6 nominations each and load and speed 5.

Question 20 asked participants about their boots, 9 out of the 10 considered their boots to be broken in, this is despite 60% experiencing blisters (figure 9.7). This suggests that even if boots are broken in then blisters will occur and it is either the distance walked or a combination of load, steps taken, stride length or speed that will determine blister rates. Knapik et al (1995) say that infantrymen are at high risk to develop blisters due to the high external masses carried and prolonged periods of activity, which increases both the number and magnitude of shear cycles and increases sweat production.

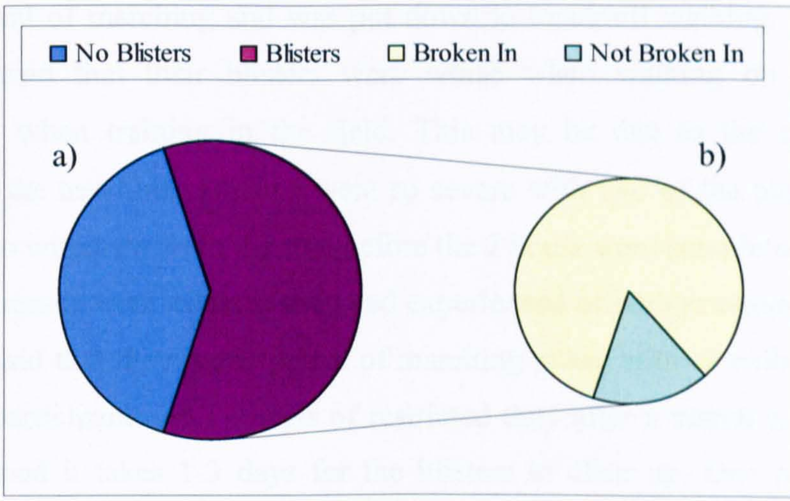


Figure 9.7: a) shows participants who experienced blisters (6/10), b) illustrates those who did have blisters who termed their boots to be broken in (5/6).

Interview Study

The development of blisters, especially on the heel and balls of feet, were common with 5 out of 8 participants from the interview study experiencing them. Of those who did have blisters 4 said that their boots were broken in and at least 6 months old (figure 9.8). These results are very similar to those reported in the questionnaire study mentioned above.

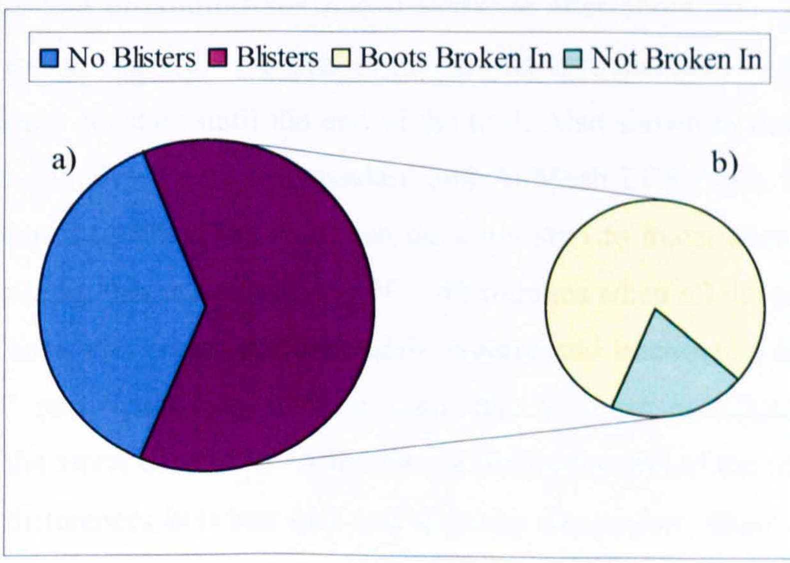


Figure 9.8: a) shows participants who experienced blisters (5/8), b) illustrates those who did have blisters who termed their boots to be broken in (4/5).

Another issue raised was that all those who experienced blisters said that they were very typical of marching either with or without load but only at the heels and balls of the feet. Two participants mentioned the formation of blisters on the toes, this was not typical of marching and was put down to treadmill walking. Another three participants said that their blisters were worse when walking on the treadmill compared to when training in the field. This may be due to the increased heat produced by the treadmill. Blisters were so severe with two of the participants they were forced to withdraw from the trial before the 2 hours were completed.

Participants were asked if they had experienced blisters previously. All 5 who had blisters said that they were typical of marching either with or without a load. Of these 5 one participant had 1-2 days of restricted duty after a march with load and 2 more mentioned it takes 1-3 days for the blisters to clear up. One participant had visited the clinic in the past and 3 others said that they were self-manageable. The remaining 3 participants who did not experience blisters on the current trial also mentioned that they rarely developed blisters at other times when marching either with or without a load. Again the formation of hot spots at the feet were cited as a particular problem. Participants considered these to be very separate from blisters, and not a 'pre-blister'.

Figure 9.9 shows the increase in foot discomfort for all participants (mean for all 6 zones and both trials) as the trial progressed. As can be seen there is a steady increase in discomfort mainly due to the development of blisters and hot spots. The graph suggests foot discomfort starts to materialise after about 30 – 45 minutes of marching, as this is where the gradient of the line starts to increase. The gradient then remains relatively constant until the end of the trial. Also shown in the figure is data for those who completed both the standard and AirMesh LCS trials. The pattern of increases is almost identical but foot pain does not start to materialise until 60 – 75 minutes of walking, this is compared to 30 – 45 minutes when all the participants are considered. Those who completed both trials experienced fractionally less discomfort than the 'All' participant line. This is again due to those participants who were experiencing the worst discomfort withdrawing before the end of the trial. Figure 9.9 suggests key differences between foot and shoulder discomfort. Shoulder discomfort onset is almost instantaneous and rises more steadily over time (less steep gradient), also a slight plateau in shoulder discomfort may also be seen. Foot discomfort takes longer to develop but seems to rise at a sharper rate, a plateau or levelling off of foot pain is not as evident.

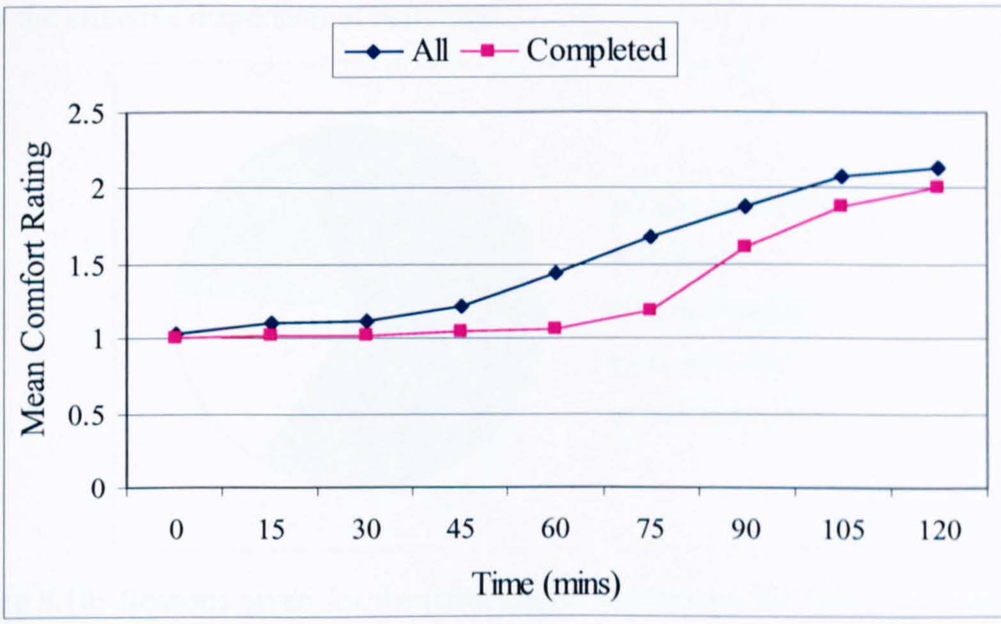


Figure 9.9: Change in mean foot discomfort over time for all participants and those who completed the trial from the interview group.

9.4.4 Answers to Questions Regarding LCS

Questionnaire Study

The first question in this section asked the participants if they have ever carried loads in packs other than the standard LCS outside of this trial. Eight of the participants had carried load in a variety of other packs including Lowe Alpine, Eurohike, Karrimor and Vango. Of these participants all of them preferred their own 'Civi' pack to the '90 Pattern Bergen. Numerous reasons were given for this preference, figure 9.10 shows their responses. It is interesting to see that the main reason for their preference is due to the increased comfort of their own packs. The other 3 main contributors are also linked to comfort, these were; reducing pain caused while marching, better padding especially in the shoulder and lower back region, and improved fit. However, potential bias should be considered, as soldiers are notorious for degrading standard issue equipment. These data show that designers of future and new LCS need to pay particular attention to the comfort and fit of a pack and not just its size, functionality and integration. When only carrying webbing, 7 out of 10 of our participants would prefer to carry load in the vest webbing, the remainder in the waist webbing. Reasons for this were that the load was more evenly distributed and equipment more easily accessible. A negative response was that vest webbing did not allow the effective dispersion of body heat.

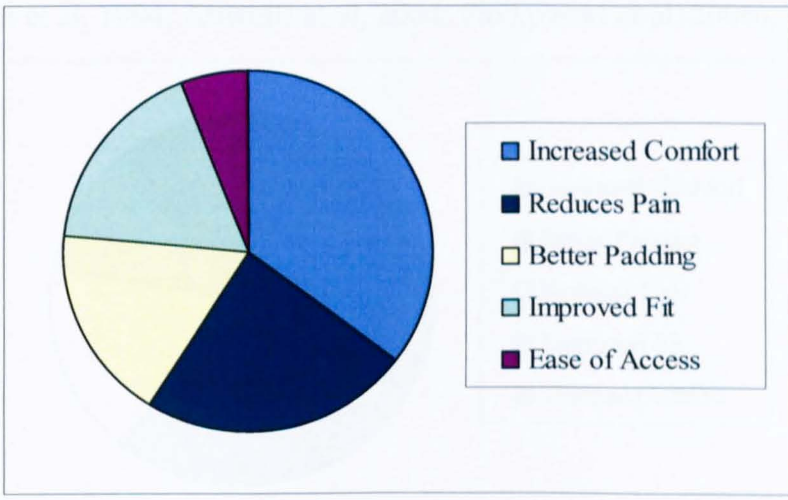


Figure 9.10: Reasons given for the participant's preference for their Civi packs over the standard LCS.

Of the two packs used in this trial 9 of the participants preferred the AirMesh LCS and one stated no preference. Previous work has shown that the AirMesh LCS has been rated significantly more comfortable by both military and civilian populations (Jones, 2005). The main reasons given for the preference of the AirMesh during the current study were increased comfort, better padding and reduced pain (figure 9.11). The AirMesh LCS has the following design features that may explain the reasons for the participants stated preferences. A functional hip belt transfers a proportion of the load from the shoulders to the hips, thus reducing the load supported by the shoulders. The hip belt may also reduce the horizontal and vertical excursions of the pack relative to the body. An insecure LCS may attenuate the sheer forces at the shoulder-pack interface and/or reduce repetitive collision with the lower back during walking, this effect may be more apparent during running or other more dynamic activities. Other differences are inserts in the shoulder straps that keep their form under loading and help to more evenly distribute the load across the strap, thus reducing both peak and mean pressure on the shoulder (Martin, 2001). Also, improved thermoregulatory aspects are gained by the new material used for the underside of the shoulder straps and back region. Finally, a block sits the pack away from the back allowing increased airflow. The AirMesh LCS is worn with vest webbing, this locates some of the load anterior on the body. This more even distribution of the load is biomechanically more favourable, and also induces the more upright walking posture which can reduce stress placed on the musculoskeletal system of the back (Kinoshita, 1985; Harman et al, 1994; Attwells et al, 2004; Fiolkowski et al, 2006).

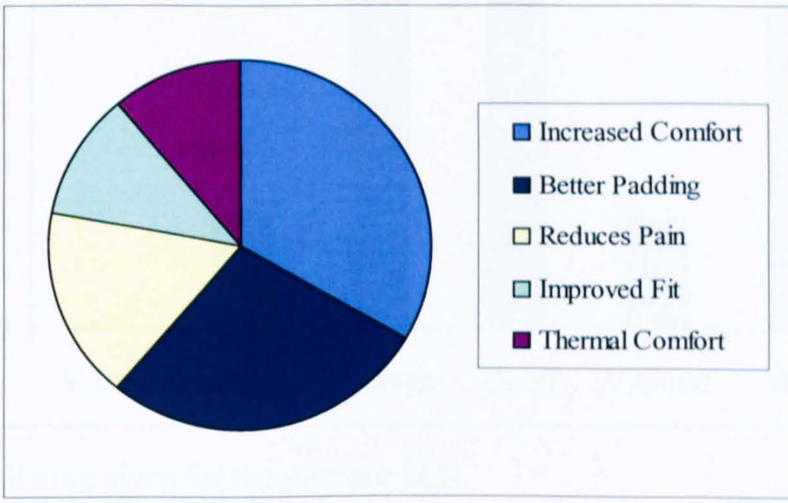


Figure 9.11: Reasons given for the participant's preference for the AirMesh LCS over the standard LCS.

The participants were then asked to rate the standard LCS out of 5, with 1 being very bad and 5 very good. The average score given was 3.5 or between average and good (figure 9.12). They were also asked to suggest improvements to the '90 Pattern Bergen, answers given were as follows: Better waist protection; a chest strap; improved waist belt; reducing the weight carried by the shoulders; improve the fit of the LCS; back section like the AirMesh; and better shoulder padding. Many of these improvements are things that can be seen on many commercial packs, some of which they may have already used to carry load in, or indeed on the AirMesh. All these aspects should be considered when designing a new LCS.

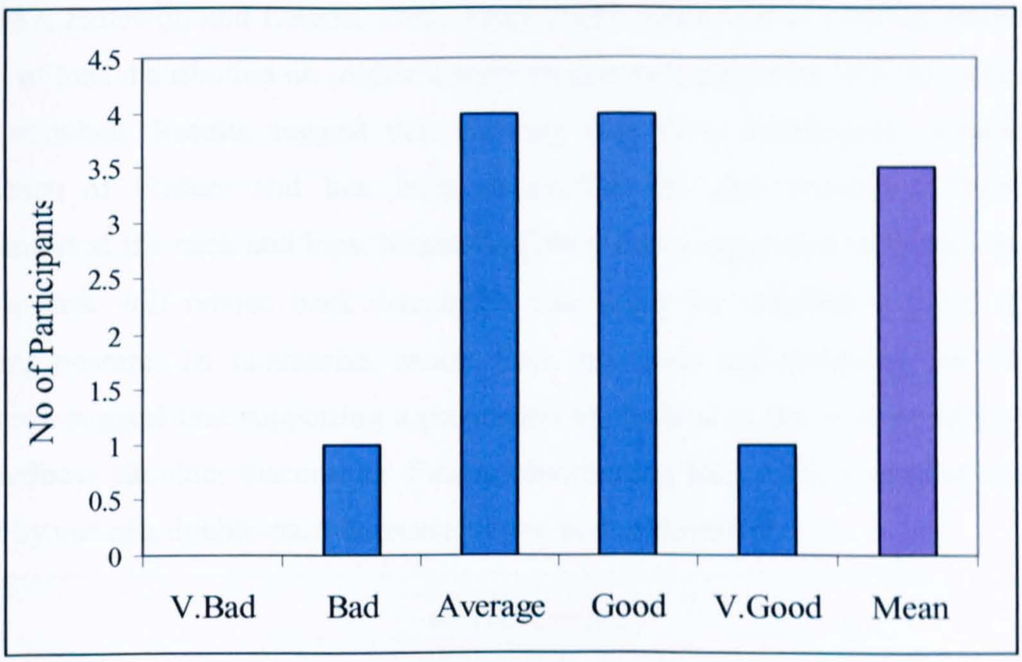


Figure 9.12: Rating given for the standard LCS.

Interview Study

During the interview study 5 out of 8 of the participants had carried the AirMesh at some time and were eligible to compare the packs. Of these participants 80% (4/5) preferred the AirMesh to the standard LCS, and one stated no preference. Quoted here are some of the reasons given for their preference: 'There was a lot less pain in the shoulders and back'; 'Increased shoulder padding'; 'More comfortable and decreased the height of the pack'; finally, 'Shifts the weight forward and onto the hips, also more padding in the shoulders and back'. Although the AirMesh LCS was preferred there were problems with the associated vest webbing cutting into the neck of the carriers. Participant 3 cited the forced forward position of the head inducing neck pain as well as the webbing cutting in. One participant also stated that the vest webbing increased his thermal discomfort.

The main reason again for the preference of the new AirMesh pack given by the soldiers was the increased comfort in the shoulder region. Figure 9.13 shows the mean comfort ratings for the 3 shoulder zones, with the AirMesh is consistently lower than the standard LCS. At the end of the trial the AirMesh LCS is over 0.3 lower for the comfort rating than the standard LCS. Potential reasons for this have been outlined in the questionnaire study section previously. Other studies have shown that supporting the load at the hips with a hip belt reduces shoulder discomfort (Bessen et al, 1987; Holewijn and Lotens, 1992; Jones 2005). Knapik et al (1997a) studied the effect of load distribution on soldier's performance during a series of 20 km strenuous road marches. Results suggest that carrying load in a double-pack reduced the incidence of blisters and low back discomfort but also resulted in increased discomfort at the neck and hips. Kinoshita (1985) also suggest that carrying load in a double-pack will reduce back discomfort and injury by inducing a more upright walking posture. To summarise, results from this study and reviewing the relevant literature suggest that supporting a proportion of the load at the wait by using a hip belt reduces shoulder discomfort. Finally, distributing load more evenly around the trunk by use of a double-pack decreases lower back discomfort.

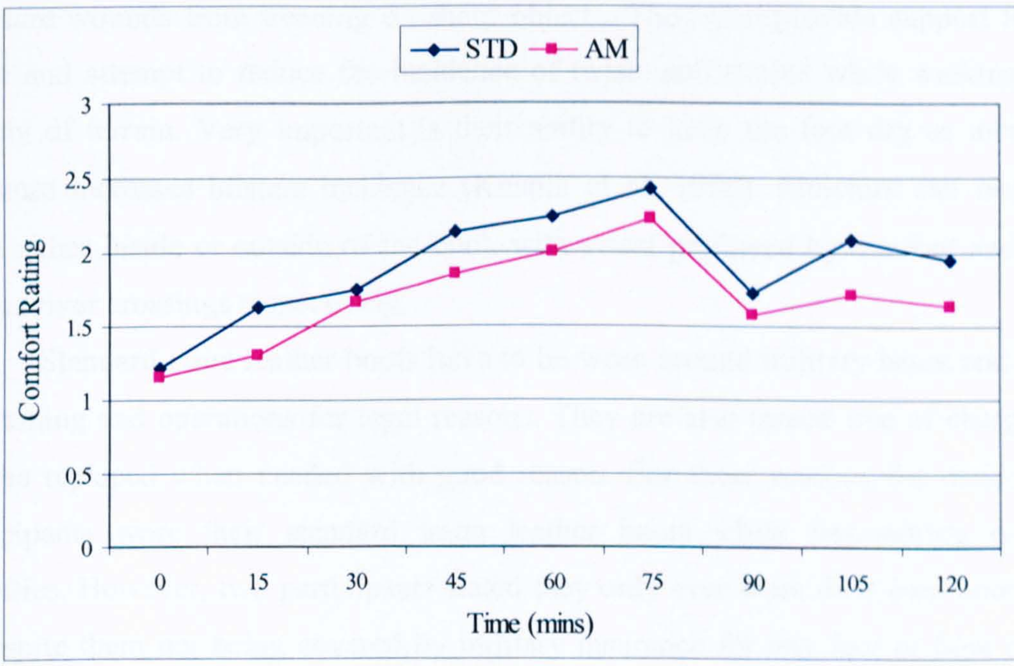


Figure 9.13: Change in mean shoulder discomfort for all participants with time for the standard and AirMesh LCS for those who took part in the interview study.

As well as asking what aspects of the new pack they liked, the soldiers were also asked how they think the current issue '90 Pattern equipment could be improved. The resounding thought was that increasing padding in the shoulder and/or back regions would be a great improvement, as this was mentioned by 5 of the 8 participants. A more experienced soldier (13 years of service) said that the webbing did not integrate well with the Bergen, as the straps from the Bergen made the yoke of the webbing cut into the neck. None of the participants had ever carried load in a short back Bergen before as they were all issued with long backs, this was surprising given most of the participants were of below average height. This may indicate a poor fit of the LCS which can in turn increase discomfort. Two soldiers also mentioned they purchased and like using the day sacks as they are a very useful size.

9.4.5 Answers to Questions Regarding Boots

Questionnaire Study

As we have seen in previous sections blisters and foot problems are a major issue among the military population. Boots are very important as they protect the foot from acute injuries such as breaks from heavy items being dropped onto the foot and puncture wounds from treading on sharp objects. They also provide support for the ankle and attempt to reduce the incidence of twists and strains while walking on a variety of terrain. Very important is their ability to keep the foot dry as increased moisture increases blisters incidence (Knapik et al, 1995). Moisture can originate from either inside or outside of the boot, with sweat produced by the foot and from rain or river crossings respectively.

Standard issue leather boots have to be worn around military bases and while on training and operations for legal reasons. They are also issued free of charge and can be replaced when needed with good reason. For these reasons the majority of participants wore their standard issue leather boots while undertaking military activities. However, two participants stated they only ever wore their own boots, this is despite them not being covered by military insurance for any foot or boot related accident. All but one of the participants considered their boots to be broken in. This participant was no longer involved in the military so wore a pair of standard issue boots from the Load Carriage Laboratory.

Insoles that fit inside boots are not standard issue and will only be issued on medical advice, or if the soldier suffers from overuse injuries. One reason why commercial boots may be preferred is for the cushioning properties of these insoles. Not only may the insoles help to relieve joint pains and reduce stress fractures but they may also help prevent the development of blisters. Many soldiers purchase their own insoles to wear with issue boots. Within this sample, 7 of the 10 participants placed insoles inside their boots and they were issued by the military to 6 participants. Windle et al (1999) showed that placing a Sorbothane® insole inside military boots significantly reduced peak pressures while marching with a load. They suggest this may reduce stress transmitted through the tibia and lead to reduced incidences of stress fractures. A large randomised trial conducted in 1988 by Gardner and colleagues found that although peak pressures were reduced, there was no reduction in the incidence of stress fractures within Marine Corps recruits. Whether or not the placement of shock absorbing insoles inside boots actually reduces stress fracture rates over the long term is debateable, with the literature remaining inconclusive. Cushioning insoles may give other benefits apart from reduced pressures. These may include: increased perceived comfort levels; reduction in blistering; improved heat and sweat dissipation. For these reasons and the potential benefits it is recommended that insoles be used (Gardner et al, 1988).

Of those participants who have had experience wearing both their own and the standard issue boots, all preferred to wear their own (5/5). The main reason given for their preference was an increase in comfort with their own boots. Other reasons were better padding and flexibility, and a reduction in pain or discomfort (figure 9.14). Again these factors should be explored if a new boot is to be commissioned by the MoD for use by military personnel.

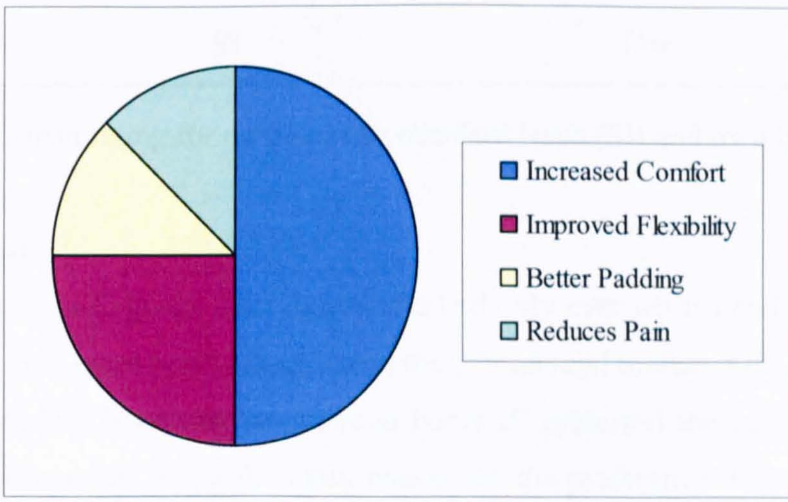


Figure 9.14: Reasons given for the participant's preference for their own boots over standard issue leather boots.

Finally, the participants were then asked to rate how good they thought the standard issue boots and if applicable (5 participants) their own boots are. The average score for the standard issue boots when rated by all 10 participants was 3.1 or average, this score however dropped to 2.4 or bad to average when rated by just the participants who have also worn their own boots. The 0.7 score decrease may be as these participants have something else to compare against, something which in their eyes is considerably better. Those participants who wear their own boots regularly rated these 4.4 or good to very good. This is not surprising as boots from the civilian market can cost as much as £150. Reasons for their preference are given in figure 9.14. These participants rated their own boots as significantly better than their standard issue counterparts, 4.4 to 2.4 out of 5 respectively (figure 9.15). Care should be taken as only 5 participants were available for this analysis.

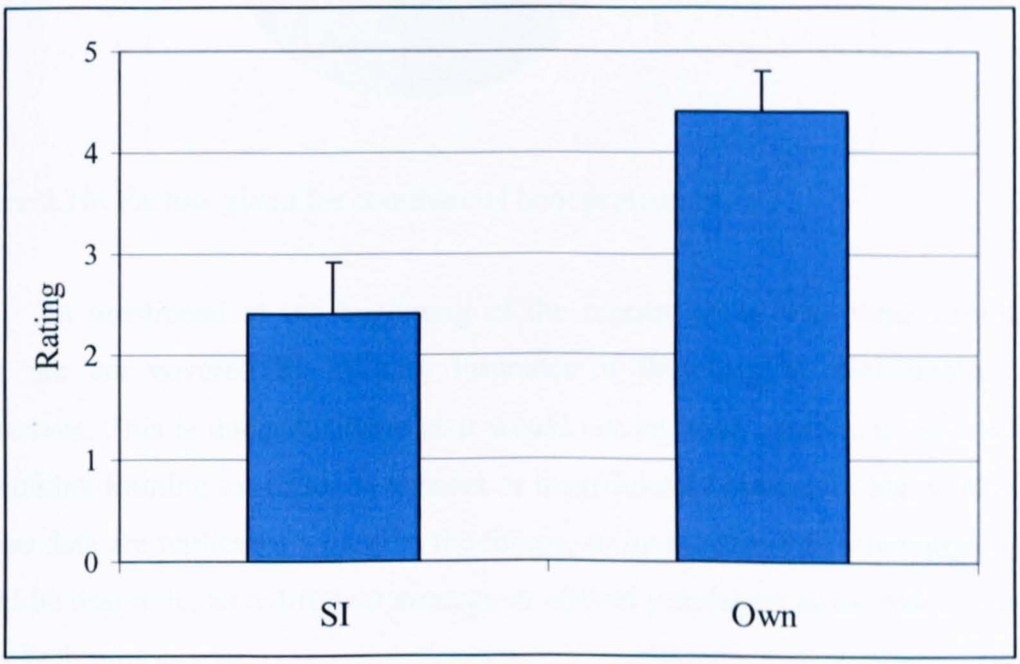


Figure 9.15: Mean rating for participant's standard issue (SI) and own boots.

Interview Study

Of those participants interviewed two had only ever worn standard issue boots and one only ever wore boots bought from the commercial market. Of those who have worn both standard issue and commercial boots all preferred the commercial boots, with increased comfort being the main reason for the preference. Figure 9.16 shows factors given for commercial boot preference. Two participants went as far as saying that wearing commercially purchased boots reduced pain and blisters while marching compared to their standard issue counterparts.

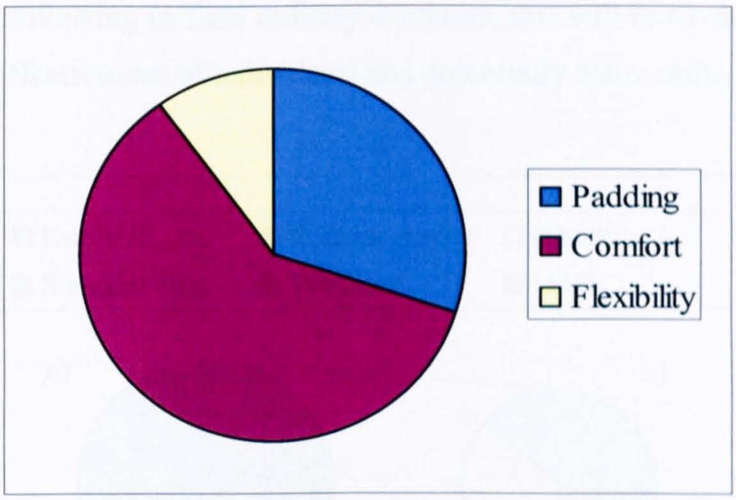


Figure 9.16: Factors given for commercial boot preference.

As mentioned at the beginning of the section those who wear commercial boots are not covered by military insurance if they trip or accidentally injure themselves. This is understandable as it would not be good practice to have soldiers undertaking training exercises in trainers or insufficiently protective boots. However, if these data are replicated widely in the forces, an investigation of alternative options would be desirable, as a different strategy or altered provisions could reduce foot and lower limb injury.

9.4.6 Answers to Questions Regarding Other Issues

Questionnaire Study

This section mainly focuses on the effects that load carriage may have on injury, and the ability of the participant to successfully complete their job. The first question asked whether they felt that carrying loads restricts their ability to complete a set task at the end of a march, either physical (obstacle course, river cross etc) or mental (map reading, rifle shooting). Half of the participants stated that load carriage did restrict their ability and the other half said no. The participants were then asked to highlight what aspect of load carriage would most significantly reduce (not necessarily restrict) their ability to complete a task. Answers ranged from load carriage increasing the incidence or severity of blisters, debilitating shoulder or neck pain, an increase in general tiredness, numbness in the hands or arms and load carriage causing injury (figure 9.17). If these data are confirmed in a comprehensive study during or following in-field military exercises, this will have clear implications for the combat effectiveness of individuals and potentially entire units.

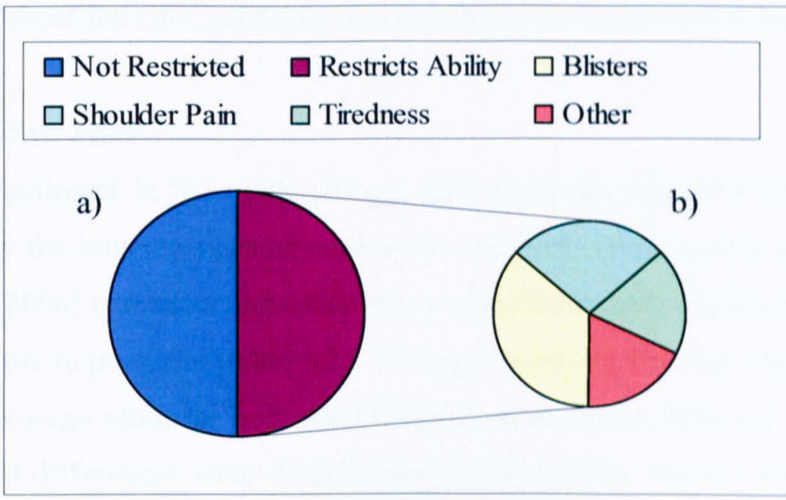


Figure 9.17: a) shows the proportion of participants who feel carrying loads restricts their ability (5/10), b) illustrates which aspect of load carriage most significantly restricts their ability.

The final questions on the questionnaire asked whether this group of participants had had any time off active duty as a result of an injury of any sort. Also, if they felt that load carriage aggravates or worsens an existing injury. All participants answered no to both questions.

Interview Study

This final section encompasses important issues raised from the interviews, commenting on the effect of carrying loads on injury rates and discomfort in particular. One of the final questions asked was to determine if carrying load caused the onset, or worsened injuries and/or discomfort; some noteworthy points were raised. Participants 2 and 8 postulate that discomfort as a result of load carriage remains constant with time but increases with load (i.e. more load carried equates to greater feeling of discomfort). While participants 1, 6 and 9 said that discomfort increases with both time and load. Participant 9 did have time off active duty due to an acute injury sustained before joining the Army. He mentioned that carrying loads alone makes this shoulder injury more uncomfortable and the more load carried, the more the pain increases. As with the questionnaire study, 50% of the soldiers thought that carrying loads significantly reduced their ability to do their job to the best of their ability. With blisters and shoulder pain being the two main reasons given. Shoulder pain specifically is a major problem as 3 participants said it affected their ability to carry, aim or shoot the rifle, primarily due to pain or numbness in the hands and arms.

9.3.7 Cognitive Tests

As mentioned in the methodology, data from the cognitive testing that was carried out by the interview participants were analysed. These results were presented by Attwells (2006) and show that there was a significant ($p<0.05$) decrease in mental performance pre to post trial (table 9.3). The significant decline was observed with the mean data (average score for both the LCS) and with results from the standard LCS. No significant differences were found when looking at the pre to post score for the AirMesh LCS alone, or when comparing the two LCS against each other. Analysis of cognitive data from those who completed the trial with both LCS suggest a trend for an increase in mental performance with the AirMesh (+1.25) and a decrease with the '90 Pattern (-3.5). However care must be taken when interpreting the latter results due to low sample size, 4 participants (Attwells, 2006).

Table 9.3: Cognitive test results, adapted from Attwells (2006).

Participant	Standard		AirMesh		Mean	
	Pre	Post	Pre	Post	Pre	Post
1	66	62	72	67	69	64.5
2	67	62	60	67	63.5	64.5
3	58	52	56	53	57	52.5
4	.	.	57	58	57	58
5	65	63	.	.	65	63
6	67	65	65	59	66	62
7	56	51	50	54	53	52.5
8	.	.	50	48	50	48
9	63	65	64	49	63.5	57
10	65	65	72	71	68.5	68
Mean	63.4	60.6	60.7	58.4	61.3	59.0
SD	4.2	5.8	8.3	8.3	6.6	6.5

Further analyses were conducted, specifically for this study, to try and establish if any correlations exist between the cognitive results and other factors. Statistical tests showed a significant ($p<0.05$) correlation between comfort and cognitive score (figure 9.18). Results suggest the more uncomfortable the participant was at the end of the trial the higher the decrement in their cognitive tests (the greater the difference between the pre and post score). This suggests the more comfortable a soldier is during a period of prolonged load carriage, the better their mental processing ability and potential decision making skills are. This has obvious implications in a military setting particularly with respect to decision making skills. There was also a significant correlation between the comfort rating at the end of the trial and whether a participant completed the 2 hour trial.

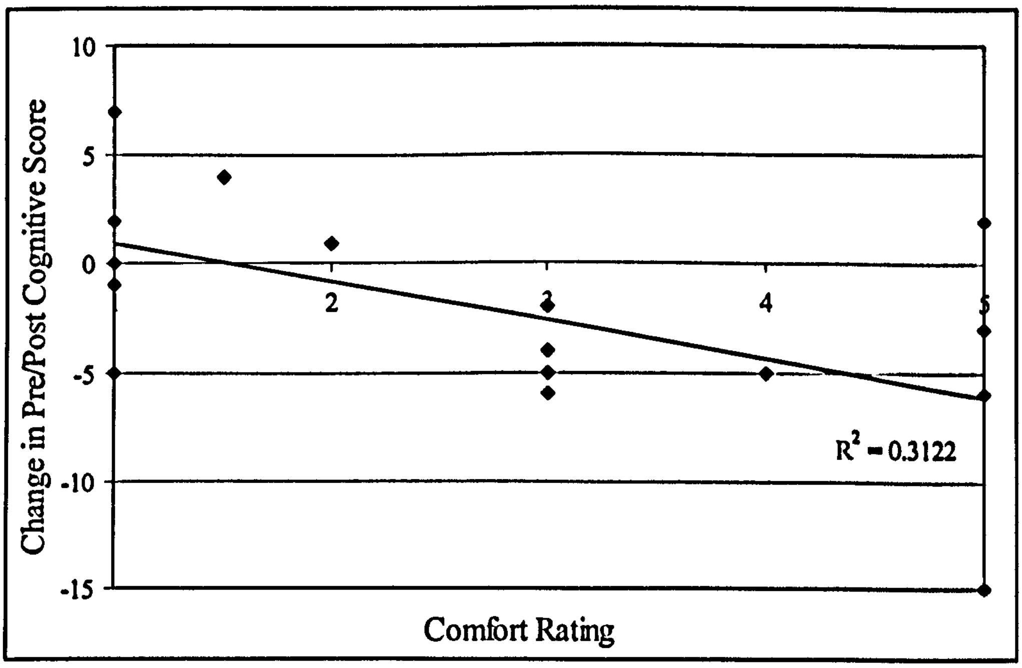


Figure 9.18: Relationship between change in pre to post cognitive score and comfort.

9.5 Conclusions

The upper limb is very susceptible to short-term injuries such as soft tissue damage and trapped nerves or blood supplies. The lower limb is not as affected by short-term discomfort but is at risk from overuse injuries. However, load carriage may aggravate or cause the onset of previous injuries, especially in the shoulder, knee or ankle. The shoulders were rated as significantly more uncomfortable then any other region. Within the interview group 50% of participants rated shoulders as extremely uncomfortable and 2 were forced to withdraw. Blisters were experienced by around 60% of participants, and for the vast majority were typical of marching either with or without load. Shoulder discomfort commences almost as soon as load is added and increases steadily with time. However, foot discomfort seems to increase more rapidly once the discomfort first materialises. In conclusion, the early development of shoulder pain or blisters may be a risk factor for severe pain or non-completion of a period of prolonged load carriage.

All of the participants questioned stated a preference for their own commercial boots compared to the standard issue counterparts, with the main reason for this being an increase in comfort. The vast majority of participants preferred the AirMesh LCS over the standard LCS, again an increase in comfort and padding were cited as the main reasons for this preference. A significant decrease in cognitive ability after a prolonged period of load carriage was observed. Also, there is a significant correlation between comfort and cognitive ability, implying the more comfortable the participant is during load carriage the less decrement in cognitive ability occurs. Finally, half of the participants stated that load carriage, in their opinion, significantly reduced their ability to complete a set task at the end of a march; the shoulder pain and blisters being the principal antagonists. Of interest to this thesis is that changes to LCS can increase the comfort of a soldier. However, rigorous testing of load carriage systems needs to be done to ensure problems are not simply shifted to another part of the body.

9.6 Limitations

During the analysis of the questionnaire data numerous points were highlighted which would add to the quality and ease of use of future efforts. Overall the questionnaire was well received and all questions were completed. However, with all research lessons can be learnt and things improved upon. Issues that were addressed for future work (Chapter 11) included:

Clarity of comfort scale – Although the same comfort scale was used throughout the questionnaire, it was only shown on the first page and needed to be referred to for questions further on. This was addressed by having participants circle a rating on the actual scale whenever asked.

Intensity not measured – Some questions asked participants to indicate which of the following would increase discomfort in a region of the body, as many options as felt appropriate could be circled. This does highlight which factors are important but does not state how much more that particular factor increases discomfort by compared to the others. This was addressed by asking participants to rate the factors out of 10 (from least to most effect); this then showed which most effects discomfort as well as by how much.

Questions regarding the lower back – During the interviews lower back discomfort was not rated as a particularly important issue with the soldiers questioned, this is most probably due to their relatively young age and little operational experience. For this reason during the pilot questionnaire questions regarding injury or discomfort to the back were limited to that of the upper back, which was grouped in with the upper limb. The questionnaire in chapter 11 was distributed to two different age groups (students and staff at Welbeck College) and also to both genders. Therefore it was deemed important that injury or discomfort to the back was included.

More focus on load carriage injuries and discomfort – The first questionnaire which was written asked questions regarding the LCS in which the load was carried and the boots worn. Although these questions raised some interesting points which were carried onto the main questionnaire such as the importance of fit and comfort of packs and boots, they were not determining how these effected or caused load carriage injuries. Their importance on the final questionnaire was reduced and the focus was firmly placed on load carriage injuries.

General layout improved – The general layout of the main questionnaire was improved by grouping questions more clearly and answers were clearly indicated in italics. Also, at the beginning of the questionnaire it was made clear that any answers given were confidential as stipulated by the Loughborough University Ethical Advisory Committee.

Extra questions added – Questions asking the participants general characteristics (age, height, weight and gender) were added, as well as more general questions regarding load carriage.

Chapter Ten – Subjective Skeletal Discomfort Survey

10.1 Introduction

The collection of data regarding skeletal discomfort during load carriage is a progression of work conducted in the previous chapter of this thesis. Chapter 9 examined primarily muscular and superficial skin discomfort whilst marching with loads in a laboratory based setting. This study builds on those findings and broadens our knowledge by focusing on discomfort to the skeletal system. Also by examining load carriage discomforts during military style exercises, these being ones conducted in the field and not a laboratory. The principal method of data collection will be a questionnaire distributed to participants following a load carriage exercise. In addition to this, data were collected from participants who failed to complete the exercise regarding the reasons for their withdrawal and their experience with load carriage. Finally, all load carriage injuries reported to the on-site medical professional in the 2 to 3 days following the exercise were logged, enabling the effect of load carriage on injury rates to be assessed. The military exercise used to collect the data was a 1-hour field march, with participants carrying approximately 24 kg. The primary aim of this study was to determine the skeletal comfort of key regions of the body that are at risk of injury after a 1 hour load carriage field exercise. This data were collected via a subjective comfort questionnaire completed immediately following the march. Other aims were to assess the impact of load carriage on dropout rates and injuries which may be sustained.

As with the research conducted in Chapter 9 the same participants and load carriage protocol formed the basis of another study conducted by a colleague in the Load Carriage Research Group (Attwells, 2006). This other study issued a comfort questionnaire to the participants derived from the body zones and comfort ratings used in Chapter 9, see figure 9.1 and table 9.2 respectively. The data collected for the current study (Chapter 10), were gained by adding additional questions to this questionnaire, thus forming one comfort questionnaire (appendix 10.1). After the completion of data collection results were separated and analysed independently.

10.2 Background

Research into the effect of load carriage on injury rates in the military seems to be lacking in the published literature. This may be because load carriage is often viewed as being a non-modifiable, extrinsic risk factor for injury. In fact many of the most detailed literature reviews and epidemiological studies fail to include any load carriage variables as risk factors for injuries. Research has shown females are approximately twice as likely as males to sustain an injury during basic military training. However, this increased injury risk has been suggested to reduce when aerobic fitness is taken into account. Stress fractures, especially to the hip, have been identified as a specific problem faced by females in the military (Deuster et al, 1997). As well as gender, the age of trainees has been identified as an intrinsic risk factor for injury. Research has shown that older trainees and younger soldiers are at an increased risk of sustaining any injury. To the present author's knowledge no study has attempted to evaluate the role that load carriage has to play in the development of injuries resulting from military exercises. Nor, assessed the incidence and prevalence of load carriage related injuries in the days following a period of load carriage. Studies which have been conducted focus on the marching itself and do not distinguish between load carriage and marching related injuries. Reynolds et al (1999) investigated the injuries and potential risk factors following 5 consecutive days of a 20-mile road march whilst carrying 47 kg. Results showed that blisters were the most frequent injury sustained, as reported by 22% of the soldiers and accounted for almost half of the total injuries. Although blisters may seem a minor ailment, following the march they accounted for 20 days of limited duty amongst the partaking soldiers.

10.3 Methodology

10.3.1 Participants

One hundred and twenty seven participants from the East Midlands Universities Officer Training Corps (OTC) were involved in the study. The participants were taking part in an annual summer camp run by the OTC, which included an activity scheduled as a 1 hour load carriage exercise. The camp took place at the Fremington Training Camp, Devon, UK between the 24th June and 3rd July 2005. The participants were already split into two categories depending on their year of study at University and therefore progression through the OTC. Both males and females were involved in the study. 'A' Company were termed the advanced group with students in their 2nd, 3rd or final year of their degree. 'B' Company or the basic group were students in their 1st or foundation year of their degrees. A small number of A Company participants completed the exercise with B Company. These participants either supervised the exercise or were those who could not attend on their designated day. As data were collected in the field only limited participant characteristics could be gained, table 10.1. The two companies conducted the trial on different days due to the logistics of the camp agenda. A Company completed the exercise at 0900 hrs on Sunday 26th June 2005 and B Company at 1000 hrs on Friday 1st July 2005. The study complied with the Loughborough University generic load carriage protocol (G03/P18) and permission was sought from OTC Commanding Officers.

Table 10.1: Participant characteristics, mean value standard deviation in parentheses.

	Age (years)	Male / Females	n
Combined	20.61 (2.55)	98 / 29	127
A	21.38 (3.66)	38 / 10	48
B	20.16 (1.40)	60 / 19	79
Male	20.67 (2.83)	-	98
Female	20.41 (1.15)	-	29

10.3.2 Protocol

The exercise conducted by the participants was the Territorial Army Combat Fitness Test (TACFT). This involved completing a 4-mile (6.4 km) field march with load in a maximum time of 1 hour, but no less than 57 minutes 30 seconds. The load carried was between 20 and 25 kg depending on the participant's regiment. This load was inclusive of weapon and ancillary items (such as helmet, boots, body armour etc); the mean load carried was 23.26 kg (± 3.0). The load was distributed between the webbing and backpack, with each participant packing their own equipment. Either

PLCE vest or waist webbing could be worn; however, only 4 participants, all from B Company, carried load in vest webbing. Three participants from each company opted to carry a proportion of the load in their day packs with the remaining participants carrying load in the Bergen.

The participants were put through a warm-up by their Commanding Officers before the exercise commenced. The march was conducted on tracks and a tarmac bridleway. The participants walked to a halfway point where there was a drinks checkpoint, and then back the same way they had come to the end point. After this, the participants could remove their load and again replenish with drinks. Again their Commanding Officers put all participants through a cool down and feet were checked for blisters. After the formalities of the exercise were complete the participants remained seated while they were given a brief overview of the research and then the Comfort Questionnaire was distributed and completed. Researchers from Loughborough University were on hand to answer any potential questions and re-collect the questionnaire once completed. The protocol was identical for both companies.

Participants who withdrew from the exercise for whatever reason were picked up by a Land Rover and brought back to the start/end point, where they could get a drink of water and rest. Here they completed the same comfort questionnaire and were asked some additional questions. At the training camp there was a medical centre that was open from 0800 until 1800 hrs, where participants could receive medical attention from a military doctor for any ailment. Before the exercise was undertaken the doctor was briefed as to the aims of the research and informed of the data that were hoped to be collected. The doctor agreed to record all visits that in his professional opinion could have been caused by carrying loads.

10.3.3 Methods of Data Collection

As outlined in the Protocol various types of data were collected using various methods, these are described below.

Comfort Questionnaire

A comfort questionnaire was distributed to all participants following the completion of the exercise. This involved rating regions of the body in terms of perceived comfort; ratings were given out of 5, with 1 being comfortable and 5 extremely uncomfortable. The current study distinguished itself clearly by examining skeletal discomfort and not general fatigue, muscle soreness or blisters. This was achieved by using a picture of a skeleton to indicate the areas in question and referring specifically to joints and bones on the question sheet (figure 10.1). The aim was to distinguish between superficial discomforts, such as muscle or skin soreness due to contact from the LCS, and actual skeletal discomfort which may have been caused by forced postures and repetitive loading of the joints. Regarding foot discomfort, efforts were made to ensure discomfort as a result of blisters or hot spots were disregarded and only skeletal foot pain was assessed.

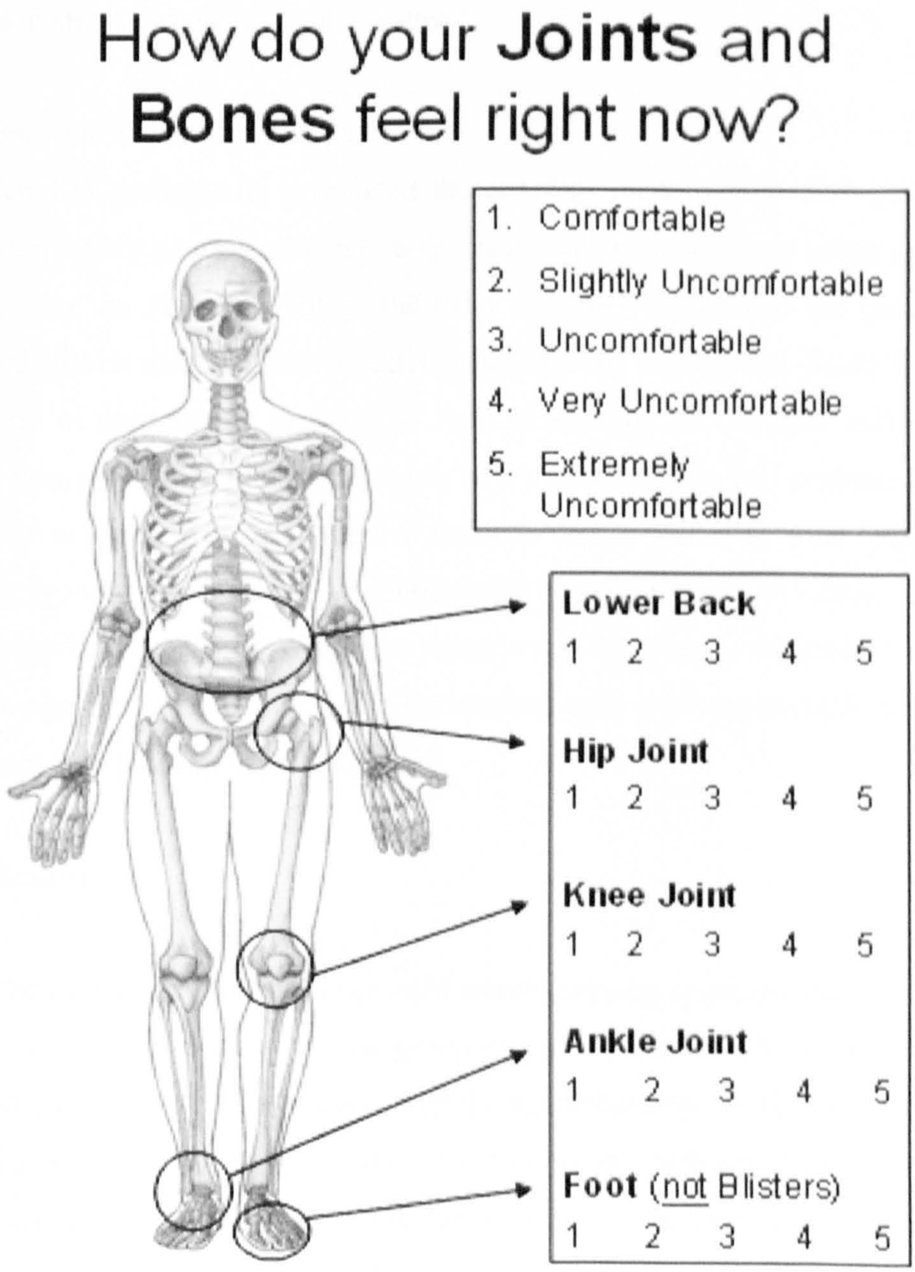


Figure 10.1: Questionnaire section used to rate skeletal discomfort.

Exercise Withdrawals and Medical Visits

Any participants who withdrew from the exercise before the designated end point still completed the comfort questionnaire and additional questions were asked in an effort to determine precise reasons for their withdrawal. See appendix 10.2 for a copy of the list of questions asked.

Instructions were left with the doctor to collect and record any visit to the clinic in the 2 to 3 days following both the A and B Company exercises. The doctor was asked to record the date, type, cause and treatment of any potential injury as well as asking the participants other load carriage related questions. Appendix 10.3 shows a copy of the information sheet given to participants and a copy of the injury information sheet completed by the doctor.

10.3.4 Data and Statistical Analysis

All 127 participants completed the comfort questionnaire. Sub-groups were identified allowing between subject comparisons to be made, these being gender and company. For the purpose of this study the 'company' of which the participant is designated will be used to determine his or her military experience. Table 10.1 shows the number of participants assigned to each sub-group. As the data collected were ordinal, non-parametric statistical tests were conducted. To evaluate potential differences between the subgroups a Kruskal-Wallis test was used. Significance within the group (or subgroups) was determined by performing a Friedman test, if this showed significance then a Wilcoxon signed-rank test was conducted to determine where the significant difference lay. All statistical tests were run using SPSS 12.0 and significance was taken at the $p<0.05$ level.

10.4 Results

The overall effect of a 4-mile field march carrying approximately 24 kg was to increase whole body skeletal in this group of participants to 1.62 (table 10.2). This represents an increase to just below slightly uncomfortable on the comfort scale in figure 10.1. Results also show that for the entire group combined the hip was rated as the least uncomfortable (or most comfortable) region of the body measured at the end of the exercise. This effect was a statistically significant one. The most uncomfortable region measured was the foot, again this difference was to a significant level.

Sub dividing the groups into gender and company (or experience) revealed many interesting findings. Interpreting the results from table 10.2 shows us that females rated both the regions of the foot and hip was significantly ($p<0.05$) more uncomfortable at the end of the march compared to their male counterparts. There were also trends for greater discomfort reported by females in the lower back and knee. There were no significant differences in comfort ratings given between 'A' and 'B' company. Both the sub-groups analysed for this study followed the same trends as seen when the group was combined. This was for the foot to be rated as the most, and hip as the least uncomfortable region of the body.

Table 10.2: Mean subjective skeletal comfort data, standard deviations in parentheses. Ratings represent comfort as assessed using figure 10.1.

	Combined	A Com	B Com	Male	Female
L. Back	1.71 (0.88)	1.63 (0.73)	1.76 (0.95)	1.64 (0.83)	1.93 (1.00)
Hip	1.46 (0.81)	1.48 (0.77)	1.44 (0.84)	1.40 (0.81)	1.66 (0.81)
Knee	1.57 (0.85)	1.65 (0.84)	1.52 (0.86)	1.50 (0.76)	1.79 (1.08)
Ankle	1.65 (0.98)	1.65 (0.86)	1.65 (1.04)	1.64 (1.01)	1.66 (0.86)
Foot	1.99 (1.19)	2.08 (1.27)	1.94 (1.14)	1.86 (1.10)	2.45 (1.35)
Body	1.62 (0.91)	1.75 (0.86)	1.66 (0.98)	1.57 (0.88)	1.80 (1.01)

In addition to the actual mean scores reported, the number of participants who gave a specific comfort rating was also assessed (table 10.3). Put simply, this is the number of participants who gave either a 1, 2, 3, 4 or 5 on the comfort rating scale for each body zone. Perhaps not surprisingly the most common rating given was 1 (or comfortable) with 57% of responses given this rating. A comparison of which participants gave comfort ratings towards the top end of the scale (uncomfortable or above) may prove to be more interesting.

Table 10.3: Percentage of participants rating body regions as uncomfortable (≥3) or very uncomfortable (≥4) or greater.

Region	Rating	Combined	A Com	B Com	Male	Female
L. Back	≥ 3	14.9	14.6	15.2	13.3	20.7
	≥ 4	3.9	0.0	6.3	3.1	6.9
Hip	≥ 3	10.2	12.5	8.9	9.2	13.8
	≥ 4	3.9	2.1	5.1	4.1	3.4
Knee	≥ 3	15.0	18.8	12.7	11.2	27.6
	≥ 4	3.1	2.1	3.8	1.0	10.5
Ankle	≥ 3	17.3	16.7	17.7	17.3	17.2
	≥ 4	5.5	4.2	6.3	6.1	3.4
Foot	≥ 3	26.8	27.1	26.6	21.4	44.8
	≥ 4	14.2	18.8	11.4	10.2	27.6

In addition to the comfort questionnaire the study aimed to gain additional data from those participants who withdrew from the TACFT, and also from the onsite medical professional in the 2-3 days following the load carrying exercise. Only one person withdrew from the exercise before its completion. This individual did complete the additional questions and this is reviewed as a case study in the discussion. In the days following the TACFT, the camp doctor recorded no case of injuries that he treated that were as a result of the exercise.

10.5 Discussion

10.5.1 The Group as a Whole

This section will discuss the results from the entire group of participants. The overall effect of a 4-mile march with load was to increase whole body skeletal discomfort to 1.62 (± 0.91), this equates to just below slightly uncomfortable. This in itself does not seem to represent a substantial problem as load carriage will cause inevitable discomfort. The key factors for military researchers are whether the discomfort is manageable, and also to determine which populations are at risk from developing more severe discomfort. This discomfort can lead to injury, either in the short or long term, or the non-completion of a set task. Other research questions that need answering by future studies may include: What will be the cumulative effect of numerous bouts of discomfort produced from successive days of load carriage? Also, what effect will increasing the load carried or distance walked and altering the terrain, gradient or thermal environment have on skeletal discomfort? Although these were not the aims of the current study, these answers will add considerably to the knowledge of load carriage and its resulting injuries. The current study will evaluate the effects a one-off, 1 hour period of load carriage has on skeletal discomfort, whilst also determining sub-populations and regions of the body that may be at an increased risk of discomfort.

Figure 10.2 shows the mean comfort ratings for the whole group combined at each body region on the comfort questionnaire. The results show that the hip region was rated significantly ($p<0.05$) more comfortable (or less uncomfortable on the comfort rating scale) than any other regions. Also highlighted is that the foot was rated significantly more uncomfortable than the other region. This suggests that the foot is an area of increased concern. With the addition of blisters to this skeletal discomfort and a soldier's preference for their own civilian boots, all factors equate to a potential problem for the UK Ministry of Defence. Reynolds et al (1999) looked at injuries and risk factors in a 100-mile infantry road march (5 consecutive days of 20-miles) whilst carrying 47 kg in an ALICE pack and webbing. At the end of the 5 days foot pain was the second most frequent injury sustained, behind blisters, with 8% of the participants sustaining a foot injury. Foot pain was also the largest single cause of limited duty days, with 22 days of limited duty after the march. The current study is in agreement with this suggesting that after a 1 hour march carrying around 25 kg the foot was the most uncomfortable skeletal region. Knapik et al, (1992) reported a 3.3% incidence of metatarsalgia after a single strenuous 20 km march.

A more surprising result was the fact that the lower back was not rated as more uncomfortable than it was, this is despite it being rated as the second most uncomfortable region behind the foot (table 10.2). This was unexpected as a study by Knapik et al (1992) showed that during a 20 km road march carrying 45 kg, 50% of soldiers who were unable to complete the march reported problems associated with the lower back. Potential reasons for the lower back results observed with this study were that the period of load carriage may not have been long enough or loads not substantial enough to cause significant discomfort. Another factor could be that the lower back may be more susceptible to successive periods of load carriage and not just a one-off bout. Finally, lower back discomfort or injury may become of increased importance with the older age, or greater experience, of a soldier. Ten to fifteen years of load carriage will inevitably place continual stress on the musculature and skeletal system of the lower back, thus potentially leading to gradual failure or chronic pain. This is supported by Songer and LaPorte (2000) who state that lower back pain is one of the leading causes of life-time compensation within the military. Participants who completed this study were of relatively young age, between 18 and 23, therefore may not experience the same persistent problems with lower back discomfort.

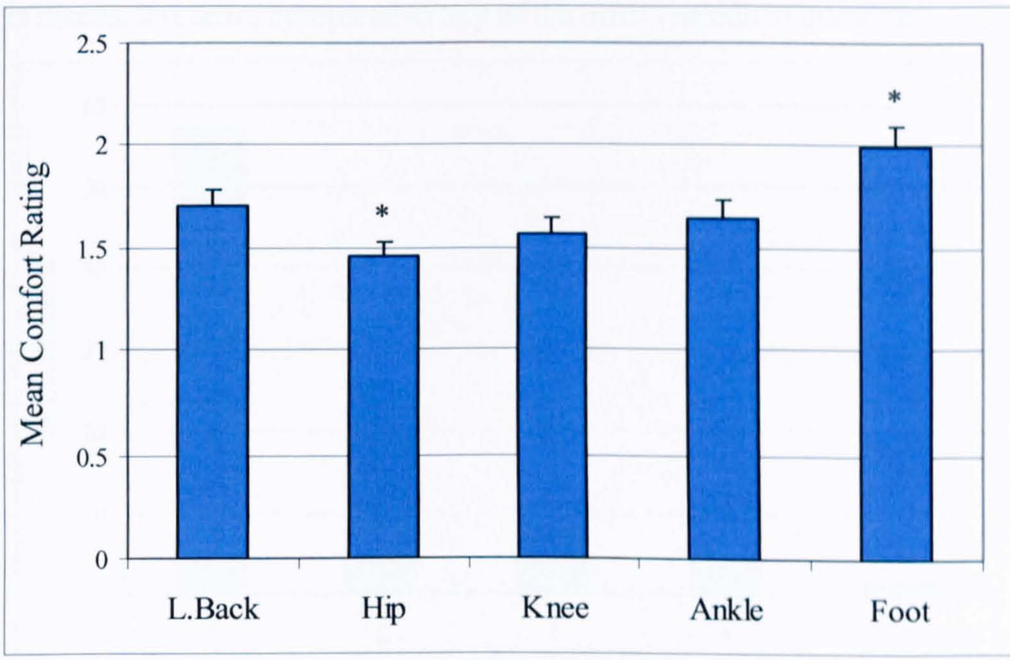


Figure 10.2: Combined mean comfort ratings for each body region, error bars represent the standard error of the data. * denotes $p<0.05$.

Further analysis of the data shows that the most frequent response given by the participants for all body regions combined was 1 or comfortable (figure 10.3). This is not surprising given the relatively short period of load carriage. More interesting maybe the number of participants that rated a particular body zone as 3 (uncomfortable) or above. This will give us an insight into which of the regions of the body experience the worst discomfort, and highlight the areas that are most at risk of injury during load carriage. Figure 10.4 shows the percentage of participants from the entire group that rated each of the regions of the body enquired about in the comfort questionnaire as uncomfortable, very uncomfortable or extremely uncomfortable (3, 4 or 5 out of 5 on the comfort rating respectively). As can be seen the hip follows the same trend as shown in figure 10.2 and exhibits the least number of responses of uncomfortable or greater. The foot also follows the same trend as figure 10.2 with this region experiencing the greatest number of 3 or over comfort ratings. On average this was around twice as many as other regions, with 26.6% of participants rating the foot as uncomfortable or greater. The percentage of participants who rated the body regions at very or extremely uncomfortable remains relatively even across the zones with the exception of the foot which received three times the number of responses than any other region. This again is reflected in the fact that the foot received the highest discomfort score compared to any of the other regions in question.

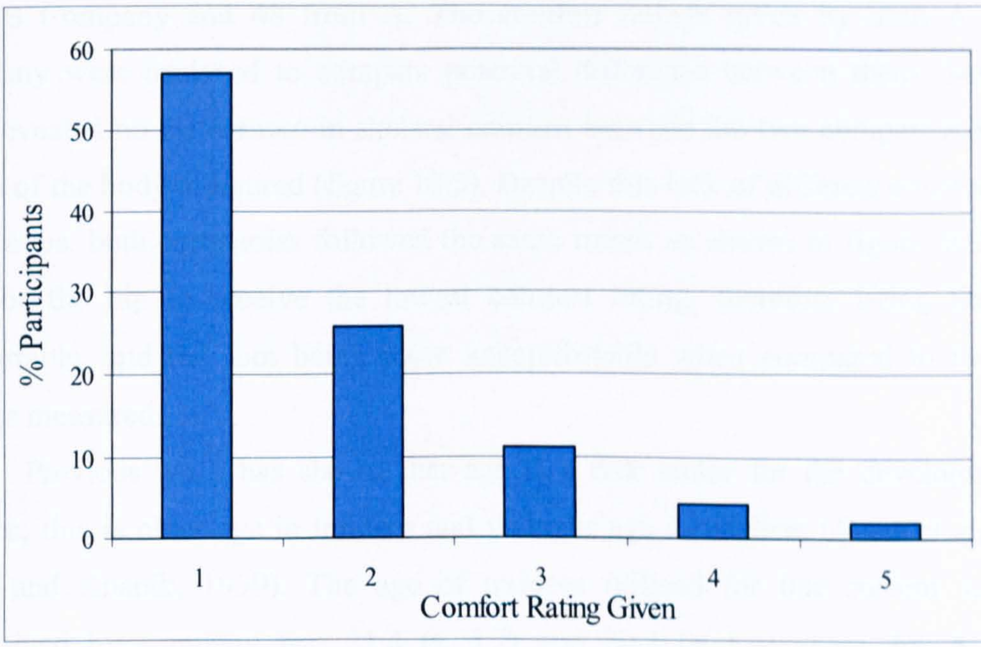


Figure 10.3: Most frequent responses given by participants for all body regions.

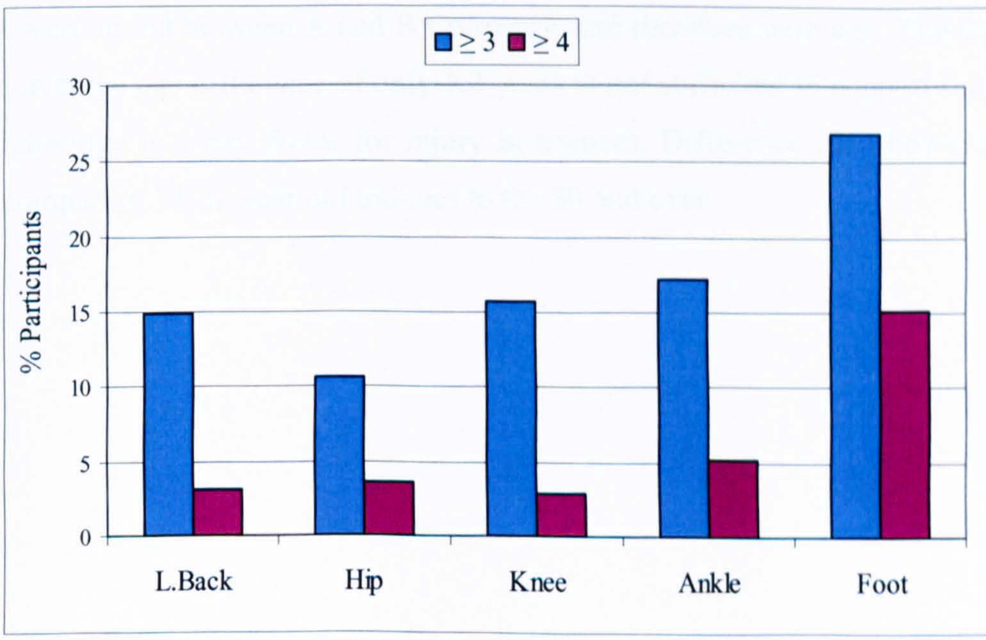


Figure 10.4: Percentage of participants that rated each region of the body at either uncomfortable (3) or very uncomfortable (4) or above.

10.5.2 A verses B Company

As stated previously the OTC were split into two companies A and B. A Company were the advanced group consisting of participants in their 2nd, 3rd or final year of their degree at university. They would have had more military exercise experience, including marching, load carriage and other essential military skills, than their B Company counterparts. B Company consisted of participants who were in their foundation or 1st year of their degrees. Sampled during this study were 79 participants from B Company and 48 from A. The comfort ratings given by both A and B Company were analysed to compare potential difference between them. Statistical tests revealed no differences in skeletal comfort between the two companies for any region of the body measured (figure 10.5). Despite this lack of difference between the sub-groups, both companies followed the same trends as shown in figure 10.2. This was for the hip to receive the lowest comfort rating, therefore being the most comfortable, and the foot being more uncomfortable when compared to the other regions measured.

Previous work has shown that age is a risk factor for the development of injuries; this is older age in trainees and younger age in soldiers (Jones et al, 1993; Jones and Knapik, 1999). The age of trainees utilised for this current study as determined by company was 21.4 (± 3.7) and 20.2 (± 1.4) years, for A and B Company respectively. As mentioned above no significant differences in the comfort ratings were found between A and B Company, and therefore with age. This suggests that an average age difference of only 1.2 years is not sufficient to support the theory that higher age is a risk factor for injury in trainees. Difference may however exist when comparing 18-21 year old trainees to the 30 and over.

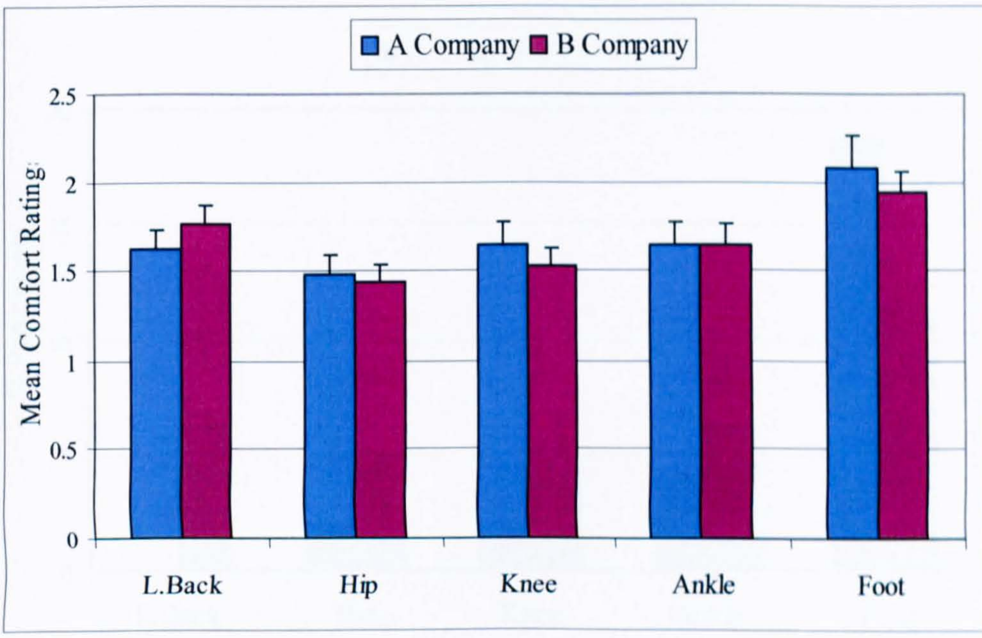


Figure 10.5: Combined mean comfort ratings for each body region as given by A and B Company, error bars represent standard error of the data.

Again the number of participants who rated each of the regions at very uncomfortable (4) or greater were analysed. This time the difference between A and B Company is assessed. Figure 10.6 shows that for the lower back, hip, knee and ankle A Company were consistently lower in the number of participants who rated these regions as very or extremely uncomfortable. This is reversed when considering the foot with more participants from A Company rating it 4 or over. The most interesting issue to arise are the responses given regarding the lower back. Not one participant from A Company rated the lower back as very uncomfortable or greater, whereas 6.3% of participants from B Company did. This may indicate an adaptive response with greater experience. These responses may include strengthening of the back muscles or more practical adaptations such as better knowledge of load distribution within the LCS or coping strategies when mild discomfort does occur. However, it is again worth indicating that no significant differences were observed with any body region between companies.

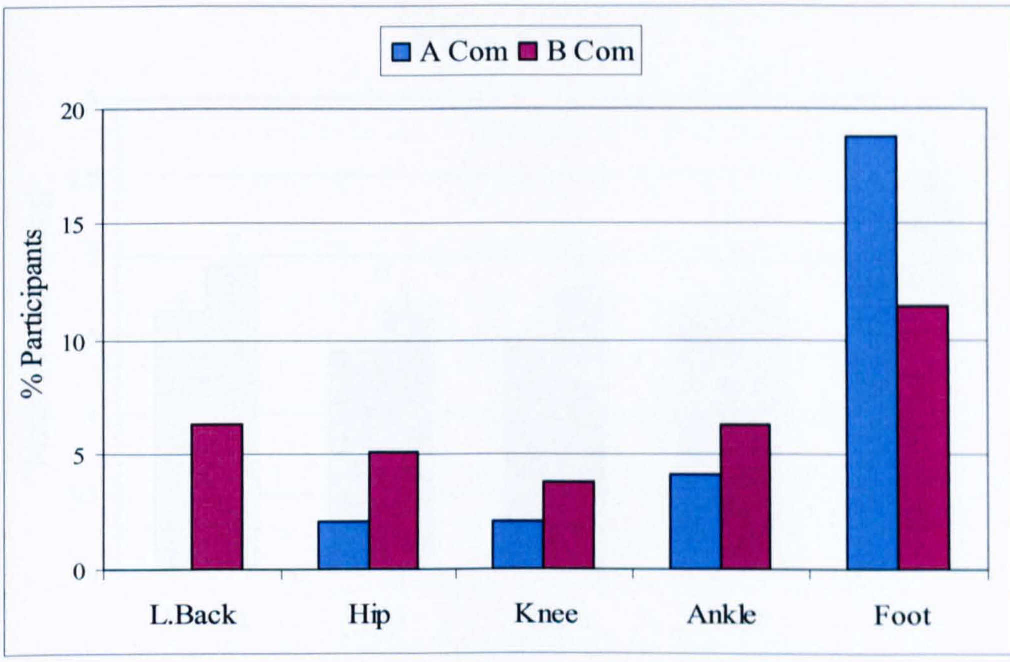


Figure 10.6: Percentage of participants from A and B Company that rated each region of the body at very uncomfortable (4) or above.

10.5.3 Male verses Female

A total of 29 females and 98 males from both A and B Company took part in the study, no difference in age or relative experience was present between genders (table 10.1). This study enabled the comparison of the skeletal discomfort experienced between genders following a 1 hour period of load carriage to be examined. Results showed that females experienced statistically significantly greater discomfort in the hip and the feet compared to males. They also showed a trend for increased discomfort in the lower back and knee regions (table 10.2 and figure 10.7). The reasons for these differences may be a result of physiological or biomechanical differences which are causing these heightened feelings of discomfort, or simply that females were more honest about the discomfort they were feeling. When reviewing the group as a whole the hip was rated as significantly less uncomfortable than any other region. However, when analysing the females on their own this was not the case and the hip was only significantly more comfortable than the foot (as were all the regions).

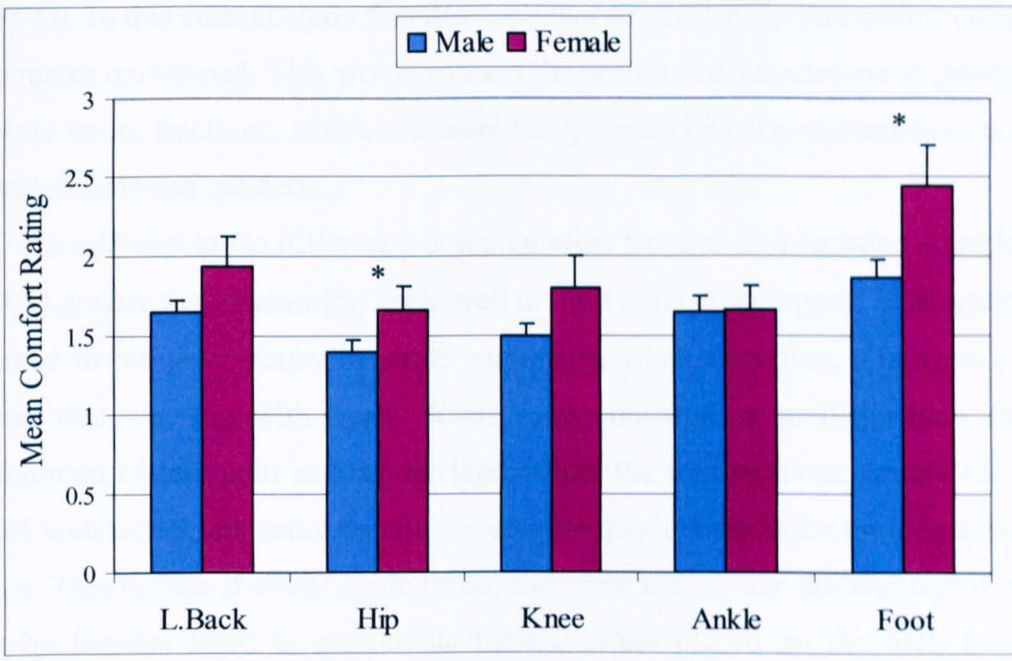


Figure 10.7: Combined mean comfort ratings for each body region as given by males and females, error bars represent the standard error. * indicates significance ($p \leq 0.05$).

Studies have shown females to be at an increased risk of injury during basic military training compared to males; this increase in risk has been shown to be around two times greater in females (Jones and Knapik, 1999; Bell et al, 2000; Knapik et al, 2001). A review by Deuster et al (1997) highlighted that stress fracture rates were higher in females and these also represented a larger percentage of the musculoskeletal injuries that were sustained. More specifically pelvic stress fractures are a particular problem concerning females in the military. Pelvic stress fractures can occur when increased shear forces are exerted on the pubic rami by the hip abductors and the hamstrings (Kelly et al, 2000). Also, females have lower bone densities and consequently are less able to resist stress and their muscle mass is physiologically weaker and more readily fatigued (Jones et al, 1994). Significant problems are also associated with marching. Marching pace is usually set by the males. This puts females at an added disadvantage due to their shorter leg lengths, and therefore reduced preferred stride length. In order to maintain pace with the group females will either increase their stride length or stride frequency, this increases risk of pelvic stress fractures (Pope, 1999; Kelly et al, 2000). A study by Martin and Nelson (1986) showed that at a fixed walking speed females have significantly shorter stride lengths and increased stride frequencies compared to males when carrying loads ranging from

0 to 36 kg. In this current study females experienced greater hip discomfort compared to the males questioned. This would support the notion that females are at greater risk of pelvic stress fractures, which are most likely caused by the discrepancy in stride parameters between genders.

In addition to the difference in hip comfort females also reported significantly ($p<0.05$) greater foot discomfort compared to their male counterparts. This again may be linked to the discrepancy in stride parameters when marching. Kinoshita (1985) showed that walking with heavy loads may constitute a predisposition for the development of foot pain as load carriage causes the foot to rotate around the distal ends of metatarsals, exposing them to greater mechanical stress for prolonged periods of time. This occurs at every stride taken, therefore the greater the number of strides taken by females leads to greater mechanical stress placed on the foot. It is also suggested that a greater maximum braking force (GRF in the anteroposterior direction) increases the movement of the foot inside the boot, thus increasing the shear forces produced, Knapik et al (1997b). This was originally thought to have an impact on blisters but may be just as relevant to metatarsalgia. An increase in maximum braking force has been seen with forced increases with stride length (Martin and Marsh, 1992), again placing females at an increased risk of developing foot injuries. The above factors are potential biomechanical reasons why females in this current study experienced significantly greater foot discomfort compared to males.

As well as the significant differences in hip and foot discomfort stated above females also showed a non-significant trend for greater discomfort in the lower back and knee (figure 10.7). This may be a result of physiological factors (weaker muscles, less muscle mass or lower bone densities) or biomechanical reasons (q-angle or kinematic changes).

10.5.4 Non Comfort Questionnaire Results

As stated in the results section only one participant could not complete the load carriage exercise, this was a 20 year old female from A Company. The main reason given for her withdrawal from the exercise was general fatigue, as she had just completed the 5 Peak Challenge a few days before the TACFT. The 5 Peak Challenge involves climbing the 5 highest mountains in the UK in 3 days; this left her dehydrated, hungry and sleep deprived. This participant was generally regarded by her superiors as one of the stronger members of the group and they felt she would have completed the exercise with ease with it not being for her exertion days before. As well as general fatigue causing her withdrawal also cited was muscular discomfort in the lower limb. This discomfort was a direct result of strenuous walking or marching, and she felt that load carriage increased these feelings of discomfort. Although this feeling of muscular discomfort had occurred before it was not typical of marching with or without load, and had never resulted in a medical visit or time off. The final questions were concerned primarily with load carriage. Firstly she did not feel that load carriage caused the onset or reoccurrence of a previous injury but believed it does restrict her ability to complete a set task at the end of a march. The aspect that most significantly restricted her ability was shoulder and neck pain. Finally, she did not feel that she would have been able to complete the task if she were not carrying load. Although no conclusions can be draw from just one persons experience it does highlight the effect that repeated bouts of strenuous activities, which may include load carriage, has. This includes impeding the performance of soldiers during exercises, causing non-completion of tasks or increasing the feelings of discomfort.

No load carriage related injuries were reported by the on-site medical professional in the 2 to 3 days proceeding the exercise. When the doctor was originally consulted regarding recording this data he was very receptive to the research being conducted, and stated he would record any injuries that in his opinion were as a result of carrying loads. Therefore we can only assume that no participant reported any such injuries and conclude that a 1 hour march whilst carrying between 20 and 25 kg is not sufficient to cause an injury that needs to be treated by a medical professional.

10.6 Conclusions

The foot was subjectively rated as the most uncomfortable skeletal region following a 1 hour march carrying around 25 kg. Despite the hip being rated as the most comfortable region by the group as a whole, this was not the case when analysing just the females. In fact the females reported hip discomfort to be significantly greater than their male counterparts. The military experience of the participants, as deemed by the Company they were in, had no difference on the mean perceived comfort ratings of any of the measured regions. However, differences were observed when considering those who rated comfort as very or extremely uncomfortable. Finally, only one participant withdrew from the exercise and no one reported a load carriage injury in the 2 to 3 days proceeding the exercise. This leads to the conclusion that although a 1 hour period of load carriage causes significant discomfort it is not sufficient to result in non-completion of the task or cause injury.

Chapter Eleven – Injury and Discomfort Questionnaire[6]

11.1 Introduction

The primary purpose of this study was to collect load carriage injury and discomfort data from both experienced and relatively inexperienced load carriers via a questionnaire. Participants who took part in the study were male and female students, (aged 17 or 18), and staff (aged between 21 and 38) at a defence 6th form college. The participants were asked to reflect on their previous experiences of load carriage, and in particular two weeks of military style exercises conducted around 10 weeks prior to the questionnaire being completed (termed throughout as summer exercises). The questionnaire was partly based on the one distributed in chapter 9, with the addition of questions focusing specifically on the lower back. In addition to the discomfort caused by carrying loads, load carriage injuries were also recorded. This was achieved by asking participants to recall if they visited a medical professional regarding a load carriage injury, and if so, the course of treatment prescribed. For the purpose of this study an injury was defined as severe discomfort that persisted for 7 days or longer, or if the participant sort medical attention. In addition to assessing discomfort and injury at the upper limb, back and lower limb, other load carriage related questions were also asked.

This chapter is an extension of previous work, combining aspects of the original questionnaire, interviews and field based evaluation. The overall aim of the study was to collect detailed load carriage discomfort data, while also assessing load carriage injury incidence and prevalence, for this group of participants. The distribution of a questionnaire to a large sample will enable robust and representative conclusions to be drawn. In addition to these questions others were asked to determine the potential detrimental effects of load carriage on military task performance. An

[6] *Work from the following chapter presented at Ergonomics Society Annual Conference, April 2008.*

important addition to the questionnaire was a scale to the discomfort questions, this allowed not only which factor most affected discomfort, but by how much. While reaching its own conclusions, work conducted for this chapter will also act to corroborate or reject previous differences found within this thesis.

11.1 Background

Background to the relevant load carriage injury literature has been given in the previous chapters, and can be seen in considerably more detail in chapter 8. Instead of giving a brief outline of the related literature this section will focus on the relevant conclusions drawn from work conducted in chapters 9 and 10.

Chapter 9 concluded that the upper limb is susceptible to short-term injuries such as soft tissue damage and trapped nerves or blood supplies. The lower limb is not as affected by short-term discomfort but is at risk from overuse injuries. However, load carriage may aggravate or cause the onset of previous injuries, especially in the shoulder, knee or ankle. Also, that early development of shoulder pain or blisters may be a risk factor for severe pain or non-completion of a period of prolonged load carriage. There was a significant correlation between comfort and cognitive ability, implying the more comfortable the participant is during load carriage the less decrement in cognitive ability occurs. Finally, half of the participants stated that load carriage, in their opinion, significantly reduced their ability to complete a set task at the end of a march; with shoulder pain and blisters being the main culprits. Chapter 10 concluded that the foot was subjectively rated as the most uncomfortable skeletal region following a 1 hour march carrying around 25 kg. Despite the hip being rated as the most comfortable region by the group as a whole, females reported hip discomfort to be significantly greater than their male counterparts. The final conclusion was that although a 1 hour period of load carriage causes significant discomfort it is not sufficient to result in non-completion of the task or cause injury.

11.2 Methodology

11.2.1 Participants

The questionnaire was completed by 100 participants from Welbeck Defence 6th Form College in Loughborough, Leicestershire. Of these participants the majority were students (n = 90) with the remainder (n = 10) staff. Of the 90 students, 60 of them were males and 30 female. All students were members of the upper 6th, aged either 17 or 18 years old. Table 11.1 shows participant characteristics. The students who completed the questionnaire were not full-time soldiers, but all had experience with military load carriage. Many of the students also had some affiliation with the military outside of college.

As mentioned in the introduction to this chapter the questionnaires were completed around 10 weeks after a 2 week period of summer exercises organised and ran by the college. On average the student spent 11 days (± 2.0) on the exercise, of these around 8 days involved carrying load. Load was carried by 95% of students in standard issue PLCE waist webbing and '90 Pattern Bergen, the remainder carried load in chest webbing and Bergen. Students were also asked to give an estimation of the load they typically carried while on the exercise. This was to ensure that the load carried was typical of that carried by full-time soldiers, and that data would be representative. The average estimation of load carried by the students was 21.8 kg (± 6.4). This load is comparable to the previous studies conducted for this thesis, in chapter 9, 20 kg was carried and chapter 10, 23 kg. Almost 80% of the students were interested in joining the Army after college. The remainder were interested in Navy (10%), Air Force (7%) and Civil Service (2%). All staff who took part in the study were male, of these all bar one were either, or had previously been full- or part-time soldiers. The member of staff who did not indicate he was a member of a particular section of the military also stated he had 'lots' of load carrying experience as indicated by their response on the questionnaire.

Table 11.1: Participant characteristics, standard deviation in parentheses.

	Number	Male/female	Height (m)	Weight (kg)	Age (years)
Student	90	60/30	175.6 (9.7)	72.6 (11.3)	17.5 (0.5)
Staff	10	10/0	182.5 (4.3)	81.6 (8.7)	29.0 (5.5)

Ethical approval was granted by the Loughborough University Ethical Advisory Committee under protocol R05/P122, with the following condition: 'That it was made explicit in the participant information that completed questionnaires would be returned to the investigators directly, and would not be seen by college staff.' This was adhered to and both students and staff were informed of this condition prior to completing the questionnaire. Permission for the study to take place was also granted by the Principal of Welbeck College.

11.2.2 Protocol

Staff at Welbeck College were instructed to circulate the questionnaire when students would have sufficient time to complete it satisfactorily, in a quiet and private environment. This may have included before a class, during registration or assembly. The questionnaires were sent to Welbeck College on the 14th December 2005, and completed versions were returned on 7th February 2006.

11.2.3 Methods of Data Collection

The questionnaire utilised for data collection in this chapter consisted of 30 questions, split up into 6 categories; general, upper limb, back, lower limb, blisters and other. See appendix 11.1 for a copy of the questionnaire used for this study. The questionnaire was developed from the one distributed in chapter 9, with questions refined and others added. The main changes to the current questionnaire were clarification of the comfort scale used by participants to rate discomfort, intensity of discomfort added, as were questions regarding the back, extra questions added and general layout improved. Also, the questionnaire was more focused on discomfort as a direct result of load carriage, and not just marching. Most importantly, questions regarding load carriage injuries were added. More detail regarding the lessons learnt from the previous questionnaire are described in chapter 9, section 9.6. Table 11.2 was again used to rate comfort of the upper limb, back and lower limb.

Table 11.2: Scale used to rate comfort.

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

11.2.4 Data and Statistical Analysis

All 100 completed and returned questionnaires were coded and frequency data collated. The main focus of the questionnaire was the effect of load carriage on the subjective responses of the 90 students. Within the students group a subcategory of gender was established. The staff questionnaire responses created another subcategory. Subcategories could also be drawn between different answers to the same question, or between 2 or more regions of the body. To evaluate the responses from the questionnaire non-parametric statistical tests were used; only the student data were analysed in this way. To assess potential differences between genders a Kruskal-Wallis test was used with data from certain questions. A Wilcoxon signed-rank test established significance for the number of responses or ratings given within a specific question by the entire group. Finally, Chi-squared tests revealed the interaction between 2 subgroups within a particular question of the questionnaire. All statistical testing was conducted using SPSS 12.0, and significance was taken at $p<0.05$. Due to the relatively low numbers within the staff subgroup, no statistical comparisons were conducted with their data. This included either within the staff subgroup, or between the staff and student subgroups.

11.3 Results

Table 11.3 shows the mean comfort rating given for each zone of the body questioned, and an estimation of whole body discomfort. Ratings represent participant responses using table 11.2 as the comfort rating scale. Whole body discomfort was not questioned separately but was taken as the mean for each participant of all 9 zones of the body. Significant differences were observed with the Wilcoxon signed-rank test showing that the shoulders were rated the most uncomfortable zone of the upper limb, and hands and arms the least. The lower back was significantly more uncomfortable than the upper back, and ankles the least uncomfortable zone of the lower limb. Also, the Wilcoxon test showed that as a region the back was the most uncomfortable, and lower limb the least. The Kruskal-Wallis test revealed significant differences between the genders, with females reporting significantly more discomfort in the back region, neck and knee compared to the males.

Table 11.3: Mean subjective responses to load carriage discomfort (questions 5, 12 and 16), standard deviation in parenthesis.

		Students			Staff
		Combined	Males	Females	
Upper Limb	Shoulders	2.60 (0.8)	2.53 (0.8)	2.73 (0.8)	2.90 (1.1)
	Neck	2.36 (1.1)	2.20 (1.0)	2.67 (1.1)	2.30 (1.1)
	Hands/Arms	1.79 (1.0)	1.83 (1.0)	1.70 (0.9)	1.7 (0.8)
Back	Upper Back	2.37 (1.1)	2.23 (0.8)	2.63 (1.0)	2.67 (1.5)
	Lower Back	2.98 (0.9)	2.78 (1.0)	3.37 (1.0)	3.67 (1.1)
Lower Limb	Feet	2.17 (1.1)	2.10 (1.1)	2.30 (1.1)	2.0 (1.0)
	Ankles	1.70 (1.0)	1.63 (1.0)	1.83 (1.0)	2.33 (1.2)
	Knees	2.02 (1.1)	1.85 (1.0)	2.36 (1.2)	2.22 (1.3)
	Hips	1.98 (1.1)	1.87 (1.0)	2.20 (1.3)	2.56 (1.0)
Whole Body	-	2.30 (1.3)	2.10 (1.0)	2.43 (1.1)	2.48 (1.2)

Table 11.4 shows the number of persistent discomforts that lingered in the days and weeks following load carriage, as reported by the 90 students. A total of 67 persistent discomforts were reported by 51 participants. The back region accounted for almost half of these with 31 complaints. Table 11.5 details the injuries which have been sustained by students as a result of carrying loads, or that occurred when loads were carried. As can be seen a total of 17 injuries were reported, by separate participants, on the questionnaire. Again the lower back was the most common site for injury occurring accounting for 59% of total injuries sustained. As stated previously an injury was classed as a discomfort that required medical attention, or that persisted for longer than 7 days.

Table 11.4: Number of persistent discomfort and injuries reported by students.

	Upper Limb	**Back**	**Lower Limb**	**Total**	**No of Participants**
Discomfort	17	31	19	67	51
Injury	2	10	5	17	17

Table 11.5: Number, location, severity and treatment of injuries sustained as a result of load carriage given in response to questions 8, 13 and 17.

Injury Type	Number of Injuries	Location of Injury	Days Lasted	Medical Visit	Treatment
Upper Limb	2	Shoulders	4	Yes	Rest
		Neck	21	Yes	Physio
Back	10	Lower Back	7	No	-
		Upper Back	7	No	-
		Lower Back	7	Yes	Physio
		Lower Back	5	Yes	Rest
		Lower Back	4	Yes	Ibuprofen
		Lower Back	4	Yes	Rest
		Lower Back	2	Yes	Stretching
		Lower Back	7	No	-
		Lower Back	10	No	-
		Lower Back	21	Yes	Physio
Lower Limb	5	Knee	14	Yes	Physio
		Hip	7	No	-
		Knee & Hip	14	Yes	Physio
		Broken Ankle	90	Yes	Hospital
		Knee	7	No	-
Total	17	-	231	11	-

Finally, table 11.6 relates to questions 6 and 23 of the questionnaire. These asked participants to rank, from least (1) to most effect (10), which aspects of load carriage they considered would most increase upper limb or general discomfort. Results for staff and students are presented, but again statistical comparisons were only conducted on the student data. With respect to load carriage and discomfort to the upper limb, the students rated both speed of march and distance hauled as increasing discomfort the least compared to weight of load, time carried and gradient/terrain. Male participants reported speed as having significantly less detrimental effect on upper limb discomfort compared to females. The same significant differences mentioned above with the upper limb were seen with the aspects of load carriage that most effect general discomfort. A Kruskal-Wallis test was also used to compare the upper limb to general discomfort questions, in order to examine potential difference between the two. Walking speed was found to have a significantly greater effect on upper limb compared to general discomfort.

Table 11.6: Mean response (standard deviation in parenthesis) to which aspect of load carriage would most affect discomfort to the upper limb and general discomfort.

Upper Limb	Weight	Time	Distance	Speed	Gradient
Combined	7.13 (1.8)	6.96 (2.0)	5.69 (2.1)	5.07 (2.1)	6.61 (2.2)
Male	6.97 (1.8)	7.22 (1.9)	5.73 (2.0)	4.75 (2.0)	6.45 (2.1)
Female	7.47 (1.6)	6.43 (2.2)	5.60 (2.4)	5.70 (2.2)	6.93 (2.3)
Staff	5.20 (2.4)	6.30 (2.1)	5.90 (2.6)	5.00 (2.3)	6.80 (2.3)
General	**Weight**	**Time**	**Distance**	**Speed**	**Gradient**
Combined	7.18 (1.7)	7.01 (1.6)	6.00 (2.1)	5.74 (2.1)	6.87 (2.2)
Male	6.98 (1.8)	6.90 (1.7)	5.83 (2.0)	5.32 (2.0)	6.63 (2.2)
Female	7.57 (1.4)	7.23 (1.2)	6.33 (2.1)	6.60 (1.9)	7.33 (2.1)
Staff	5.40 (1.7)	6.60 (1.6)	7.10 (1.7)	5.70 (2.2)	7.3 (2.2)

The tables above display responses to re-occurring questions asked throughout the questionnaire. However, each section of the questionnaire asked questions specifically related to the effect of load carriage, these results will be presented now. Two questions were concerned with mobility and range of movement in the back and upper limb. Forty percent of students questioned thought that carrying loads did not restrict the mobility of their upper body. The remaining were split between load carriage restricting the movement of the head (27%), and ability to lift the arms (33%). Approximately 60% stated that carrying loads restricted the flexibility or range of movement of the upper and lower back. Participants were also asked if they worried about the long-term implications of carrying loads on their upper limb and back. Results suggest that 17 and 34% of participants did worry about the long-term effect of carrying loads on their upper limb and back respectively. For both regions of the body a further 10% of participants had not given any thought to the matter. Concluding the results with respect to the upper limb, two-thirds of participants questioned indicated that the initial discomfort (not injury) as a result of carrying load would alleviate between 1 and 30 minutes after the load was removed. One-third also stated that they had experienced numbness in the hands or arms while carrying loads. However, 60% of participants stated they did not, and the other 7% didn't know.

Another section of the questionnaire was devoted to questions regarding blisters. Just under half of the participants stated they did usually get blisters when undertaking military activities. The most common site for blister development was the heel (43%); with toes, balls of feet and sides of feet each receiving a similar number of responses. The restrictiveness of blisters on the participant's ability to march was also asked. Approximately a third of participants said not at all, a further third a little and the rest rated them as between some and very much. Ninety percent of participants suggested that blisters were self-manageable, i.e. they knew how to treat blisters when they arose, 10% took no action.

The final section of the questionnaire was concerned with the effect of load carriage on other issues such as; existing injuries, risk of falling and ability to complete set tasks. Other questions asked participants to state if they felt that carrying loads restricted their ability to complete military tasks at the end of a march. These tasks could be either physical, like an obstacle course or river crossing, or mental, for example map reading or decision making. Results showed that around 70% of participants thought that load carriage restricted their ability to complete a physical task at the end of a march, this dropped to 20% with respect to a mental task. Gender effects were also analysed, these showed that significantly more females thought that load carriage would reduce their ability to complete a mental task at the end of a march. The aspects of load carriage that most restricted a participant's ability were back pain and general fatigue with 23% of the total responses each, and shoulder and neck pain at 20%. Another question asked whether or not carrying loads increased the participant's perceived risk of sustaining a fall, and increased the severity of a potential fall. Two-thirds of participants questioned thought that carrying loads did increase the risk of a fall, while just under half thought it would increase the severity of a fall. Other results showed that 42% of participants placed cushioning insoles inside their boots. Also, that 64% of students carry loads regularly in commercially purchased backpacks. Finally, participants were asked if they had a current or previous injury that is triggered or aggravated by load carriage, or if feelings of discomfort mentioned in the questionnaire occurred during other non-military activities. For both questions around 30% said they did and 70% did not.

11.4 Discussion

The questionnaire distributed for this chapter of the thesis revealed many interesting and important findings. Results showed, and further discussions will elaborate, that the lower back was the region of the body that caused the most discomfort, sustained the majority of injuries and was the area that caused the most concern to the participants questioned. Participants were also considered load carriage to significantly impede their ability to complete a physical task at the end of a march. With heavy loads, long durations and difficult gradient and terrain most affecting discomfort during load carriage. Of interest to this thesis were the incidence and prevalence of load carriage related injuries. Approximately 20% of student participants reported at least one injury of any sort; in addition to 67 cases of persistent discomfort, experienced by 57% of participants.

The results presented above will be discussed in 4 main sections: Results from student questionnaires, results comparing males to female students, results from the staff questionnaires and finally results regarding injuries. Within the student results section of the discussion responses to all questions will be commented upon, other sections will highlight important and interesting findings only.

11.4.1 Results from Student Questionnaires

Reviewing the results presented in table 11.3 shows that the lower back was rated the most uncomfortable region of the body during a typical period of load carriage by this group of participants. The combined mean subjective response given was 3 out of 5, or uncomfortable using table 11.2. The second most uncomfortable region were the shoulders at 2.6, joint third were the neck and upper back with mean ratings of 2.4. Relating these responses given to those from previous chapters is difficult. Responses given in chapter 9 were immediately following a 2 hour period of load carriage, and chapter 10 focused on skeletal discomfort following 1 hour of load carriage. However, certain observations can be drawn. Subjective comfort ratings for the shoulder were identical at 2.6 for both this current study and the study presented in chapter 9. In chapter 10 the mean comfort rating given relating to the lower back was lower, than the 3 out of 5 with this study, at 1.7. Ratings for the upper back and neck given in chapter 9 are again lower than observed in this study at 1.3 and 1.8, respectively, compared to 2.4 with the current study. Potential reasons for these differences will be discussed in the '*Back*' subsection later in the discussion.

Upper Limb

As with data presented in chapter 9 of this thesis, the shoulders were rated as significantly ($p<0.05$) more uncomfortable than other regions of the upper limb (figure 11.1). Injury to the upper limb as caused by load carriage is not frequently reported; however, discomfort is very apparent. Carrying a backpack can cause soft tissue damage and skin irritations at the backpack-body interface, namely the shoulders. Pressure from the backpack straps can cause the restriction of blood flow and trapped nerves of the arm. This can cause sensory loss in the hands which may have knock-on effects to the participant's ability to aim and shoot a rifle. A long-term effect of load carriage may be rucksack palsy; this is caused by pressure from the straps damaging the nerves of the brachial plexus. Despite shoulder discomfort being a significant problem for these soldiers, due to load carriage, the discomfort usually dissipates within half an hour. Two-thirds of student participants questioned stated that upper limb discomfort disappeared within 30 minutes of removing the load; this is comparable to results from chapter 9.

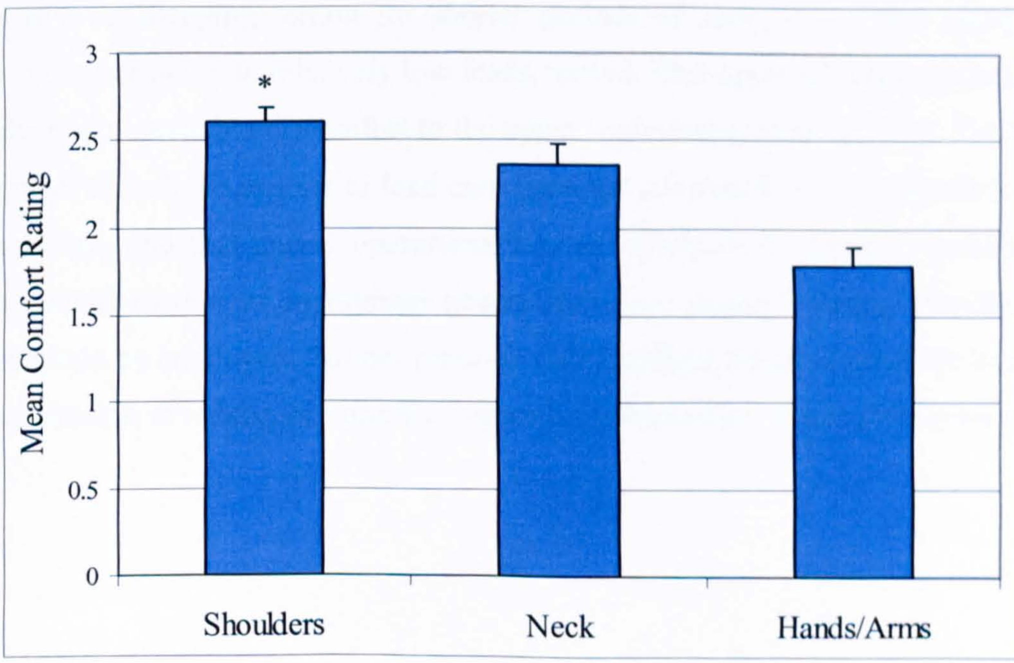


Figure 11.1: Mean comfort rating for the upper limb, error bars represent standard error. * denotes $p<0.05$.

Question 6 of the questionnaire asked students to rate out of 10, with 1 being least effect and 10 being most effect, which aspect of load carriage most increased the upper limb discomfort they typically experience during load carriage. The categories given were weight, time, distance, speed and gradient/terrain. Table 11.6 and figure 11.2 show that as one might expect weight of load has the effect of most increasing discomfort in the upper limb during a period of load carriage. Speed of march had the least effect on discomfort, as mean effect ratings given for this were significantly ($p<0.05$) lower than all other aspects questioned. Weight, time and terrain were all rated as significantly increasing discomfort compared to both distance and speed.

The interesting issue highlighted by this question is that gradient/terrain was rated as having a significant negative impact on the comfort of the upper limb. This was not necessarily expected, as it is not one of the obvious parameters such as time or weight of load. In response to these findings a suggestion put forward by this thesis to reduce the incidence of upper limb discomfort, and subsequent potential injury, is as follows. Load carrying exercises should not encompass carrying heavy loads for long periods of time over challenging terrain, with particular reference to young soldiers or trainees. This thesis suggests that only 2 of the 3 aspects that most significantly increase upper limb discomfort should be used in conjunction during a load carriage training exercise. For example, a march could involve carrying heavy loads over challenging terrain for shorter periods of time, or a long march over challenging terrain with relatively low loads carried. This approach may go some way to reduce the inevitable discomfort to the upper limb during load carriage. The author recognises that all the aspects of load carriage rated are essential for complete training programmes, and that during operations it is not likely to be possible to adhere to these guidelines due to operational needs. However, during training exercises this theory could be employed. Further research will highlight which aspects are best used in combination to reduce, or minimise, upper limb discomfort during load carriage.

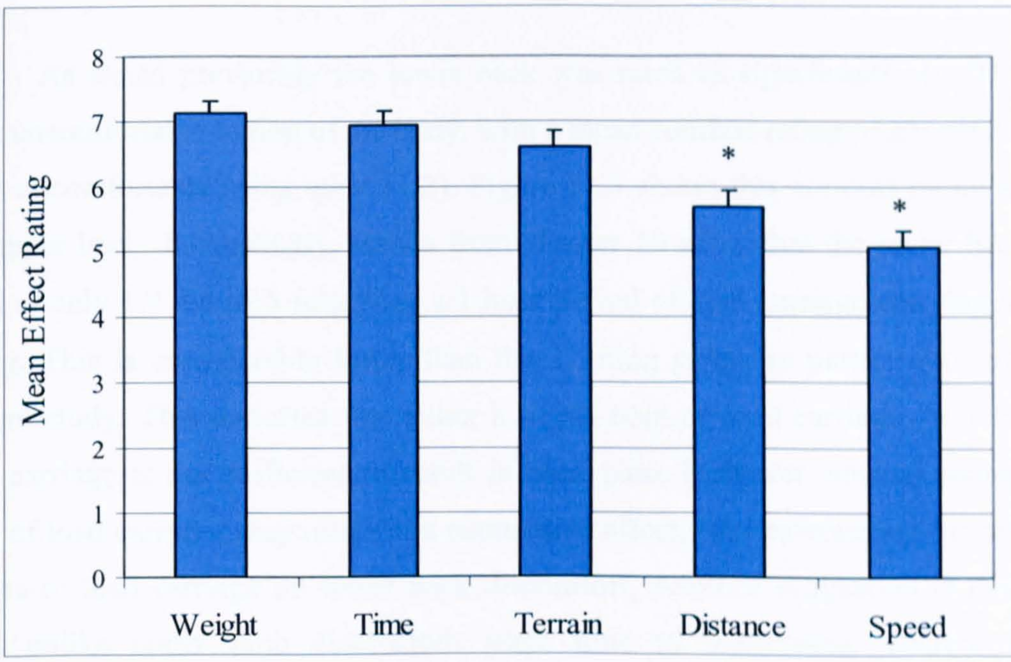


Figure 11.2: Mean ratings as to which aspect of load carriage most increased the discomfort in the upper limb, error bars represent standard error. * denotes $p<0.05$.

The final questions in the upper limb section of the questionnaire asked participants if they felt that load carriage restricted their ability to elevate their arms or rotate their head. A third of participants thought that load carriage did restrict their ability to elevate their arms. Anecdotal evidence from the interviews conducted in chapter 9 suggests that carrying a backpack restricted the ability to lift the arms when needed to elevate the rifle to aim. This was caused by the constraint of muscles or nerve compression affecting the body's ability to perform the task. This has obvious implications on a soldier's ability to aim and shoot a rifle; and as shown by this current study is experienced by one third of young trainees. Related to the previous question was question 9, during load carriage have you ever experienced numbness in your hands or arms. Sixty percent of participants stated that they did not experience numbness, with one-third saying they did. Finally in this section participants were asked if they were concerned about the long-term implications that carrying loads may have on their upper limb. Over 70% of participants stated they did not worry about the long-term implication, with 17% saying they were (figure 11.4). This again adds weight to the notion that the upper limb is more susceptible to short-term discomfort rather than long-term injury. An interesting comparison will be made later in the chapter regarding the answer to the same question regarding the back.

Back

As stated previously the lower back was rated as significantly ($p<0.05$) the most uncomfortable region of the body, with a mean comfort rating of almost 3 out of 5 (or uncomfortable using table 11.2). Figure 11.3 shows this comfort rating against the upper back. Interestingly, results from chapter 10 show that the lower back was rated at only 1.7 out of 5 following a 1 hour period of load carriage carrying around 23 kg. This is considerably lower than the 3 rating given by participants with the current study. This indicates that either a single bout of load carriage, or 1 hour of load carriage is not sufficient to result in back pain. However, several consecutive days of load carrying may result in a cumulative effect, thus extenuating the negative effects of load carriage on lower back discomfort. Another suggestion is that back pain, unlike upper limb discomfort, takes time to materialise. Therefore with questioning immediately following a period of load carriage back pain may still be limited. This issue highlights the advantages of retrospective questioning regarding load carriage.

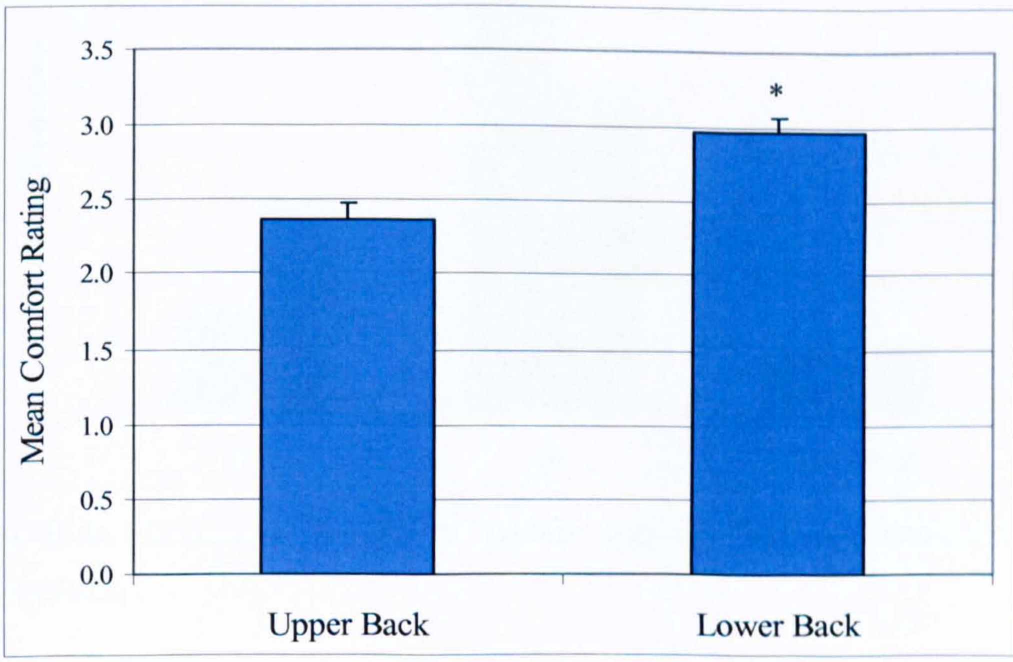


Figure 11.3: Mean comfort rating for the back, error bars represent standard error. * denotes $p<0.05$.

Two-thirds of participants questioned thought that carrying loads restricted the flexibility and movement in their backs. This was during load carriage and not after the removal of load. The implications of this are a restricted ability, or reduced speed, to carry out basic motor tasks such as bending down to the floor or side to side, or getting to and from the ground. Participants were also asked if they were concerned about the long-term implications carrying loads has on the back. As when asked the same question referring to the upper limb, the majority of participants stated that they did not. Despite this significantly more participants said they were concerned about their back compared to upper limb, 34% verses 17%, respectively (figure 11.4). These results are of interest as the student participants questioned were only 17 to 18 years of age and as yet not full time military personnel. However, these results show that a third of student participants are already concerned about their backs. This is with good reason as Songer and LaPorte (2000) state that low back pain and knee injuries are the leading cause for lifetime compensation within the US military.

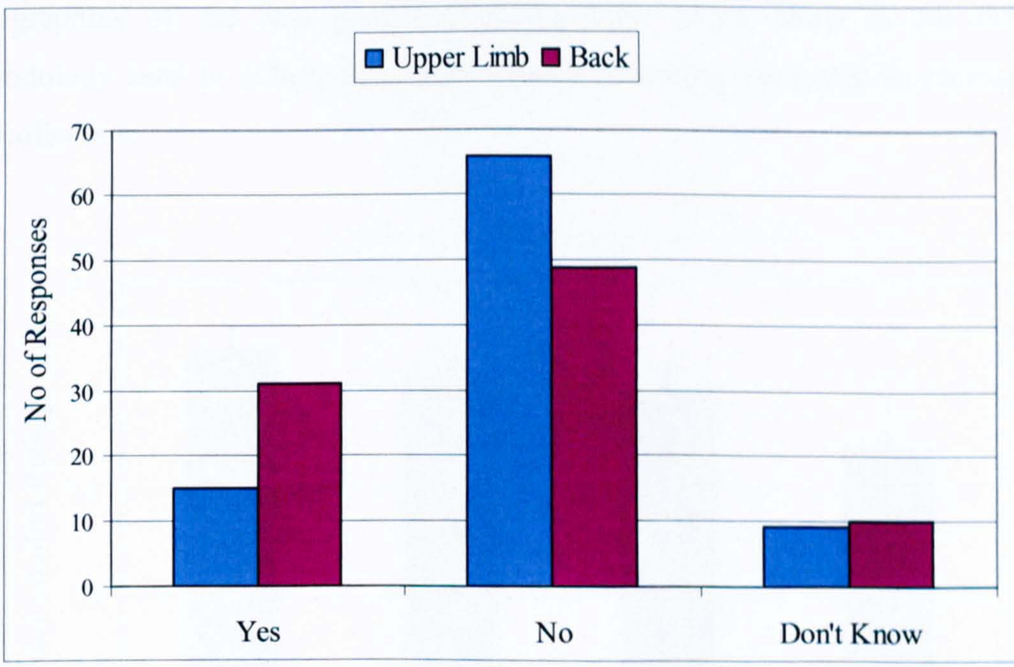


Figure 11.4: Participants response to concern over the long-term implications of carrying loads.

As suggested in Chapter 9 of this thesis different designs of LCS can alleviate certain types of discomfort. The use of a hip belt removes some of the load from the shoulders and transfers this to the hips; this has been shown to reduce shoulder discomfort. In addition, double-packs (which distribute load on the posterior and anterior of the body) lead to a reduction in forward lean and a subsequent decrease in reported lower back discomfort. As shown with this current study lower back and shoulder pain are the principle discomforts experienced by participants questioned. Further highlighting the importance of ergonomic LCS designs.

Lower Limb

The region of the lower limb that showed the greatest typical discomfort when questioned were the feet, at 2.2 out of 5. Following the feet were the knee and hip at around 2 out of 5, or slightly uncomfortable using table 11.2. The ankles were rated as the significantly ($p<0.05$) most comfortable region of the lower limb, and body as a whole (figure 11.5). These results are again in slight contradiction to those observed in chapter 10. In both chapters the foot was rated as the most uncomfortable region. However, in chapter 10 the ankle was rated as the second most uncomfortable region of the lower limb. These differences may be due to the different characteristics and demographics of the two groups of participants. More likely is the different methodology used to collect data, immediately following compared to retrospective data collection.

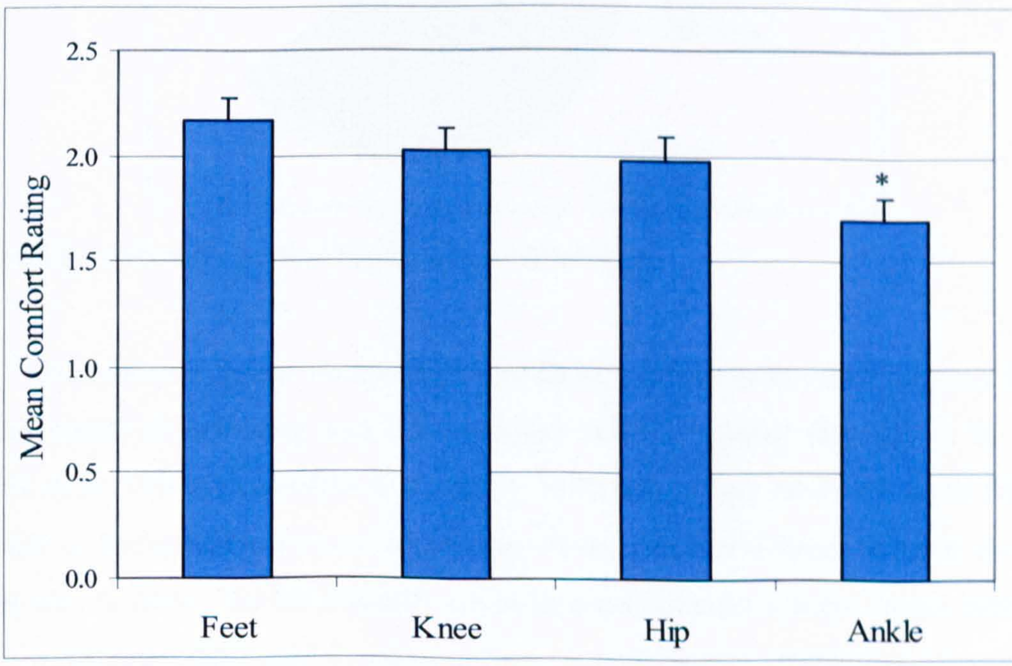


Figure 11.5: Mean comfort rating for regions of the lower limb, error bars represent standard error. * denotes significance from other conditions ($p<0.05$).

Blisters

Almost half of the participants questioned typically experienced blisters when undertaking military activities. This is consistent with results from the literature. Following load carrying exercises, of varying lengths and intensities, blisters were experienced by 60%, 69%, 45% and 22% (Chapter 9, Knapik et al, 1992; Knapik et al, 1997a; Reynolds et al, 1999). The heel was suggested as the most frequent site for blister formation from the current study, with almost half of the participants citing this. If participants felt it necessary more than one region of the foot could be selected, thus the heel accounted for 42% of all responses (figure 11.6). When blisters did occur the vast majority of participants (90%) termed blisters as self manageable, 9% took no action. Of the 90 participants questioned only 1 participant had time off due to blisters.

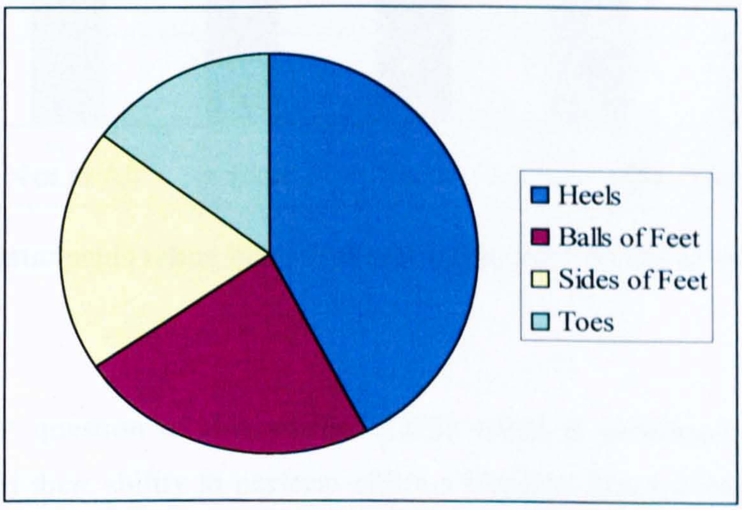


Figure 11.6: Most frequent sites for blister formation.

To soldiers blisters are not just considered a minor inconvenience, they are the leading cause of marching and load carriage related injuries (Knapik et al, 1992; Knapik et al, 1997a; Reynolds et al, 1999). With the current study the most frequent response to the question of how restricting would you rate blisters on your ability to march was 'a little'. To the majority of participants blisters are not major problems, but to a minority they are. Twenty percent of participants stated that blisters were either 'quite a bit' or 'very' restricting (figure 11.7). Chapter 9 concluded that the early development of blisters may be a risk factor for severe pain or non-completion of a period of load carriage. It is these participants to whom extra attention should be given, either by ensuring their boots are broken in and suitable (i.e. correct size etc), or blister preventing socks worn or insoles fitted. This does not have to be provided as standard issue but participants should be made aware of the potential options available.

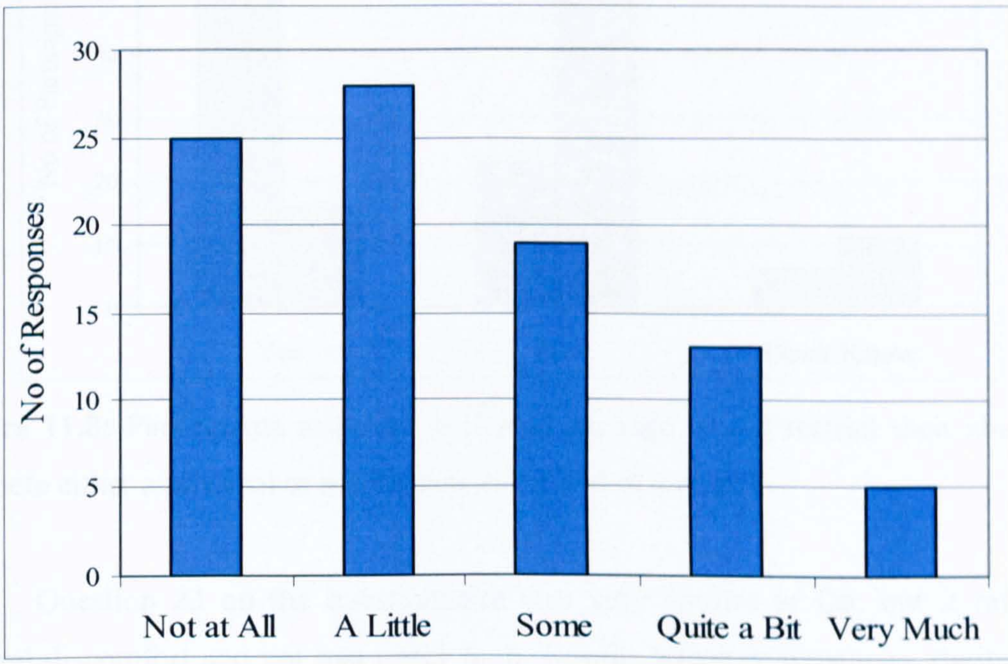


Figure 11.7: Participants rating blisters as restricting their ability to march.

Other

The first question of this section (Q22) asked if participants felt that load carriage reduced their ability to perform either a physical task (obstacle course, river cross etc) or mental task (map reading, rifle shooting etc) at the end of a march. Figure 11.8 shows the responses. Sixty-eight percent of participants thought that load carriage would restrict their ability to perform a physical task, this dropped to 18% when a mental task was considered. In both the interview and questionnaire study in chapter 9 half of participants questioned said that load carriage does restrict their ability to complete a set task (either physical or mental) at the end of the march. Combining the results from this study a total of 43% of participants agreed, therefore results between studies are comparable. This again highlights that ergonomic research to improve LCS design aimed at making the carrying soldier more comfortable will have a positive effect on improving military task performance.

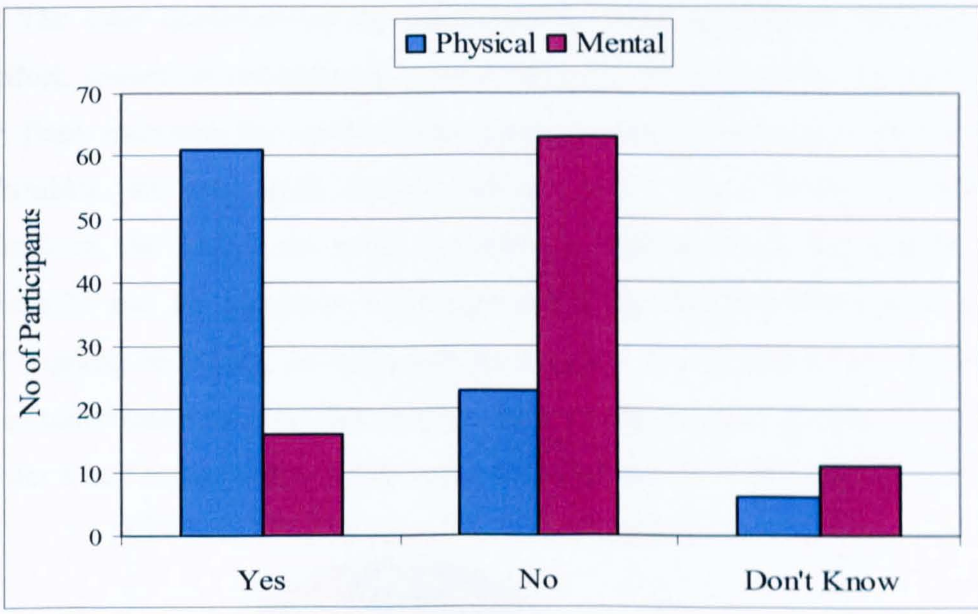


Figure 11.8: Participants response to if load carriage would restrict their ability to compete either a physical or mental task at the end of a march.

Question 23 on the questionnaire was very similar to Q6, but it refers to general discomfort and not just upper limb. Results however were very similar with weight having the most effect to increase discomfort. Both distance and speed were rated as having significantly less effect than the other 3 conditions. This supports the suggestion that only 2 of the 3 top scoring conditions should be used in combination.

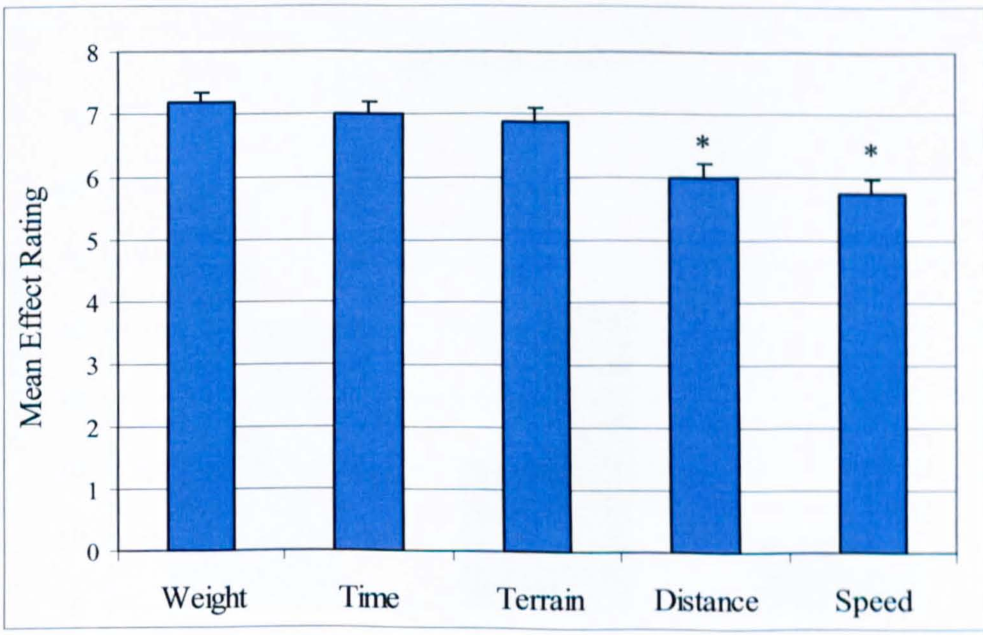


Figure 11.9: Mean ratings as to which aspect of load carriage most increased general discomfort, error bars represent standard error. * denotes significant difference (p<0.05) from weight, time and terrain conditions.

The later questions on the questionnaire asked participants which physical discomfort, caused or exacerbated by load carriage, most restricted the participant's ability. Back pain was the number one response, with an increase in general fatigue and shoulder and neck pain closely behind. Injury, lower limb discomfort and numbness in the hands or arms received the fewest responses (figure 11.10). Questions 25 and 26 related to if participants felt that carrying loads increased their risk of tripping or falling, or increased the severity of a potential fall. Almost two-thirds of participants thought that load carriage would increase the risk of a fall, with just under a half suggesting it would increase the severity of a fall (figure 11.11).

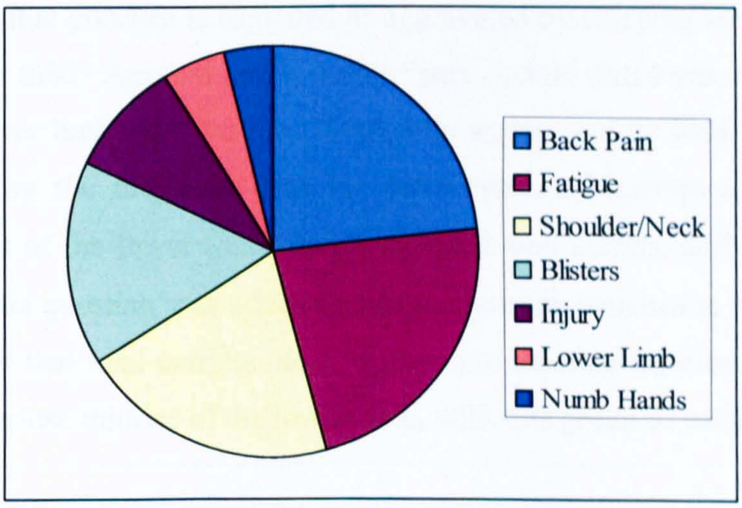


Figure 11.10: Aspects of load carriage that significantly restricted ability.

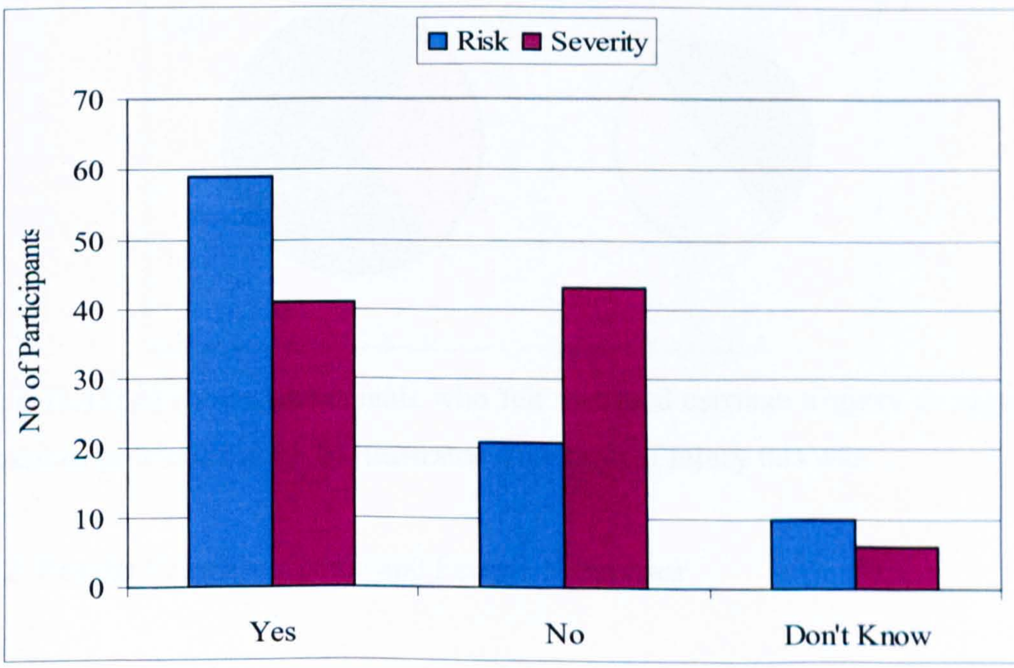


Figure 11.11: Participants response to if they felt load carriage increased the risk or severity of a fall.

Question 27 asked participants whether or not they placed additional insoles inside their boots, 42% did. It is unclear within the literature if cushioning insoles actually reduces stress fracture rates. However, results have shown an attenuation of peak forces during walking (Windle et al, 1999) and running (Cavanagh, 1987). Higher forces produced at heel strike are theoretically more likely to lead to stress related injuries (Cavanagh, 1987). Other benefits of insoles may include increased perceived levels of comfort, reduction in blisters, improved heat and sweat dissipation and the alleviation of lower limb pain such as knee pain and shin splints.

Figure 11.12 shows responses to the question 'Do you have a current or previous injury that you feel is triggered or aggravated by carrying loads? If yes what type of injury is this?' Approximately 30% of participants stated yes, of these injuries those to the lower limb were the most frequently aggravated by load carriage. It was very apparent by the responses that the main types of injuries aggravated were overuse injuries of the lower limb. These included shin splints, and ankle and knee discomforts. This question was added to substantiate the conclusion made in chapter 9, and confirms that load carriage does worsen pre-existing injuries or discomforts, particularly over-use injuries of the lower limb, with this group of participants.

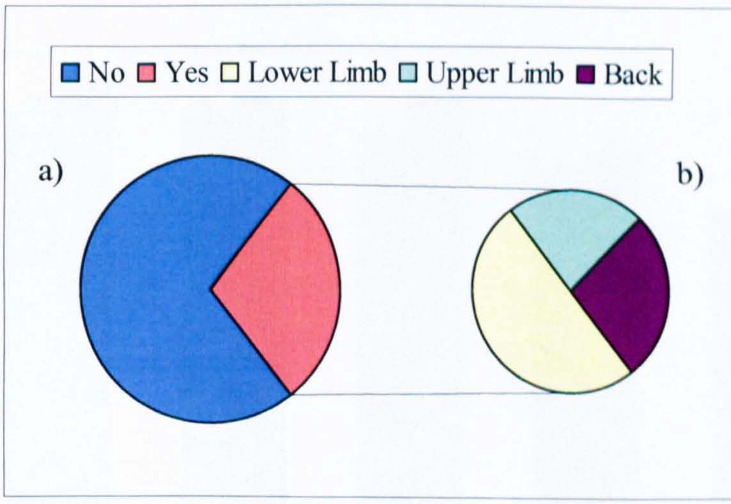


Figure 11.12: a) shows participants who felt that load carriage triggers or aggravates a current or previous injury, b) illustrates what type of injury this was.

11.4.2 Results Comparing Male and Female Responses

This section of the discussion will not evaluate all the responses given by males and females for every question, it will highlight the interesting and important findings. As mentioned earlier in the discussion responses given for the condition which most increases upper limb or general discomfort during load carriage were very similar. For this reason, only the responses to general discomfort will be compared with respect to gender. Figure 11.13 shows the general trend for females to rate all of the conditions as having a greater effect on general discomfort during load carriage compared to the males. This difference was only significant ($p<0.05$) for the speed of marching. A reason for this may be the fact that marching pace is usually set by the males or commanding officers. This speed may be faster than females would typically self-select. Females will generally have shorter leg lengths and therefore reduced preferred stride lengths compared to their male counterparts. To maintain speed females will either have to increase stride length and/or stride frequency. Research suggests that these increases put females at a greater risk of injury, in particular pelvis stress fractures (Pope, 1999; Kelly et al, 2000). This is a potential reason why general discomfort during load carriage being as a result of increased walking speed being rated as significantly greater by females compared to males.

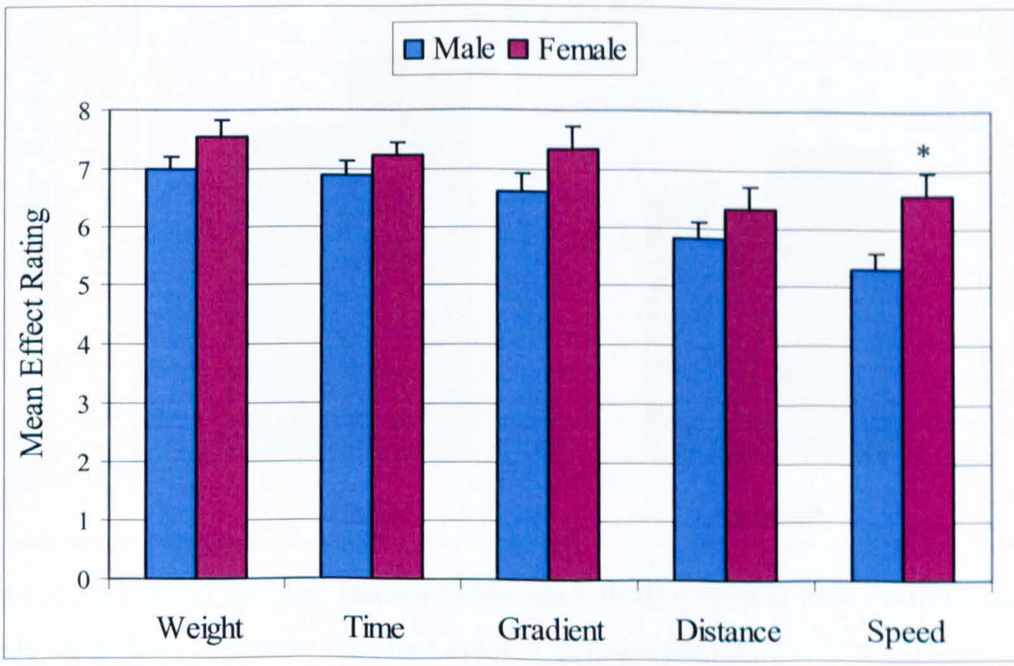


Figure 11.13: Mean ratings as to which aspect of load carriage most increased general discomfort between genders, error bars represent standard error. * denotes significant difference between genders ($p<0.05$).

Females rated both the upper and lower back as typically more uncomfortable during load carriage than males (figure 11.14). These results are consistent with the trend observed in chapter 10. Back discomfort may develop from females having physiologically weaker and more readily fatigued muscle mass (Jones et al, 1994). Another factor may be due to the greater range of motion of the trunk experienced by females whilst carrying loads (Attwells, 2006). This has been shown to cause additional stress to the back muscles (Norman, 1979; Gordon et al, 1983; Harman et al, 1992). A final potential reason may be that when carrying heavy loads backpacks do not tend to move in synchrony with the trunk (Norman, 1979), thus causing cyclic stress to the back muscles (Norman, 1979; Harman et al, 1992). This stress will again occur at every stride taken. The combined effect of females taking a greater number of strides over a set distance and weaker muscles, may lead to a compounded effect to increase female back discomfort compared to males during load carriage.

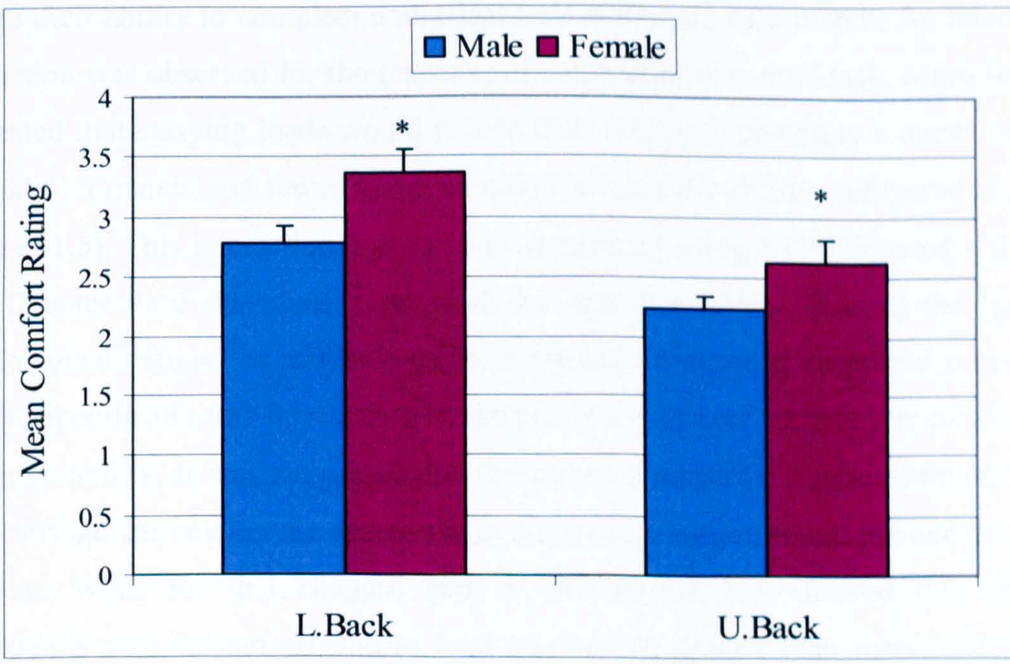


Figure 11.14: Mean comfort ratings of the back during typical load carriage between genders, error bars represent standard error. * denotes p<0.05.

In addition to the greater discomfort in the back region compared to males, females also rated the discomfort in the knee and the neck as significantly ($p<0.05$) greater as a result of typical load carriage (table 11.3). A trend for females to exhibit increased knee discomfort was observed in chapter 10. Again a potential reason for this is likely due to the weaker muscle mass of females (Jones et al, 1994); therefore, providing inadequate support for the knee joint during load carriage. Another important biomechanical factor may be the greater Q-angle with females. The Q-angle put simply is the width of the hips compared to the position of the knee. An increased Q-angle has been linked to overuse knee pain (Neely, 1998a). The increase in neck discomfort is not as easy to apportion reason to. The most likely explanation is to do increased skeletal frame size of males. A bigger, stronger and denser frame of males is going to support heavy loads easier than smaller, weaker and less dense frame of females. It is worth pointing out that not all females who enter the armed forces will be either smaller or weaker than their male counterparts.

Gender responses to question 22 ('do you feel that carrying loads reduces your ability to complete a set task at the end of a march, either physical or mental?') were also analysed. In regard to the physical factor, no interesting interactions were observed. With 70% of males and 63% of females implying that load carriage would reduce their ability to complete a physical task at the end of a march. An interesting interaction was observed for the response of completing a mental task. More females suggested that carrying loads would reduce their ability to complete a mental task at the end of a march, and fewer that it wouldn't affect their ability, compared to males (figure 11.5). This interaction was rated as significant using a Chi-Squared statistical test. Chapter 9 of this thesis and work by Attwells (2006) showed that general physiological fatigue as a result of load carriage decreased cognitive processing ability. Specifically this thesis showed the positive relationship between comfort and cognitive ability. It was suggested that the more comfortable a participant is during load carriage, the smaller the decrement in cognitive ability between pre and post load carriage. Work for this chapter, and in chapter 10, has showed that females consistently rate discomfort due to load carriage as greater than males. Also, that females consider that load carriage is more likely to affect their mental ability at the end of a march. This further substantiates the suggestion put forward in chapter 9, that comfort during load carriage has an important interaction to mental ability following load carriage.

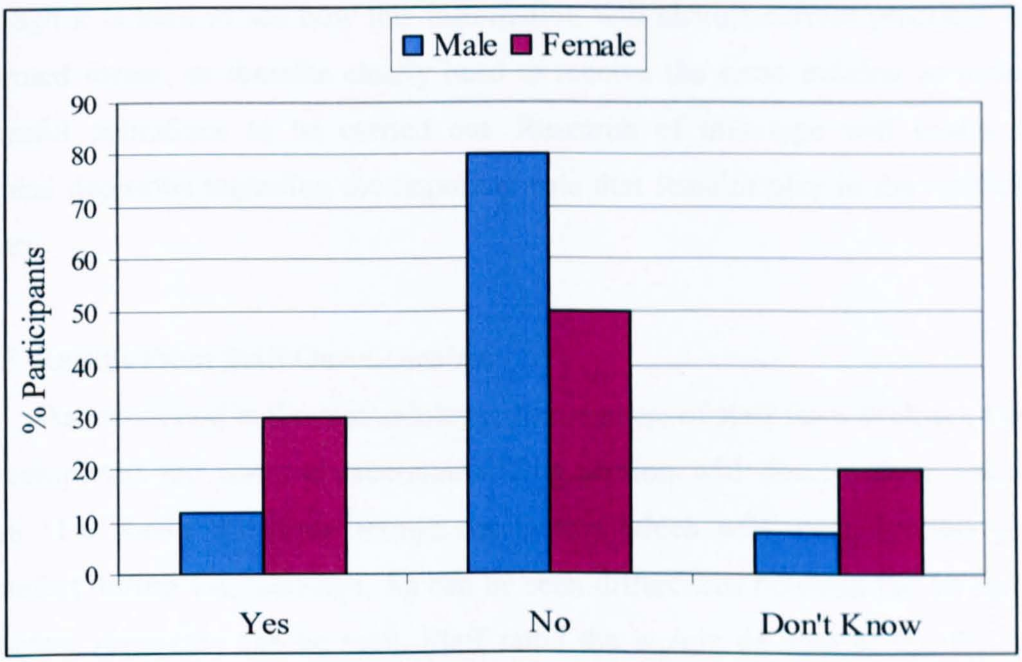


Figure 11.15: Percentage of male and female participants stating load carriage effects on completing a mental task at the end of a march.

Since 1998 females have been able to serve in approximately three-quarters of posts in the British armed forces. To this day females are excluded from serving in the Royal Marines, Infantry and other close combat roles. Numerous reasons were given for this decision, including determinants of load carrying ability. Previous studies have shown females to be 1.5 to 2 times more likely to sustain an injury during basic training compared to males (Jones and Knapik, 1999; Knapik et al, 2001). Reasons given for this fact include female lower bone densities, and that their muscle mass is less, physiologically weaker and more readily fatigued than that of males (Jones et al, 1994). Also, generally females will be less physically fit than their male counterparts (Bell et al, 2000). In the military no special dispensation is given to females regarding physical training. They have to carry the same loads, march the same distances at the same speeds and conduct many of the same tasks as their male counterparts. Work in this thesis has shown that females rate discomfort as a result of load carriage as greater than males immediately after load carriage (chapter 10) and retrospectively (this chapter). This is in addition to the known effects on injury rates. It should be pointed out that physical fitness, and not gender, has been suggested as being the major risk factor for the development of any injury (Jones and Knapik, 1999; Bell et al, 2000). The most physically fit females will have the same injury rates as males.

Although it is hard to see how this information will change current practices within the armed forces, as females clearly need to receive the same training as males for successful operations to be carried out. Research of this type will enable more informed decisions regarding the important role that females play in the modern day military.

11.4.3 Results From Staff Questionnaires

As mentioned in the methodology, 10 members of staff from Welbeck College also completed the same questionnaire. This section will discuss their responses. Figure 11.6 shows the mean ratings for factors which will most increase general discomfort during load carriage. As can be seen differences between the 10 staff and 90 student responses can be seen. Staff rated the weight of load as the factor that would have the least effect on their general discomfort, for the students this had the greatest effect. Large discrepancies between staff and student responses can also been seen for distance, with staff rating this as having more of an adverse effect on comfort compared to the students. Interestingly, gradient/terrain was rated as having the most effect on general discomfort during load carriage. The fact that the staff rated weight of load considerably lower than the students may be due to physical development and load carriage experience. Many of the staff who completed the questionnaire were ex-members of the military, and all staff rated themselves as having 'plenty' of load carriage experience. The average age of the staff was 29 years old and obviously being more physically developed. Load carriage experience and physical strength seem to reduce the impact of carrying heavy loads. Gradient and terrain was rated by the staff as having the most effect on discomfort. This combined with the student response, of gradient and terrain being the third most significant aspect to increase load carriage discomfort, make for surprising findings. This highlights the limitations of lab based studies using treadmills for collecting subjective load carriage discomfort data, as rough or difficult terrain cannot be simulated. However, lab based studies are essential for research as they have the ability to control for many variables. This highlights the need for both laboratory based and in-field studies when considering military load carriage.

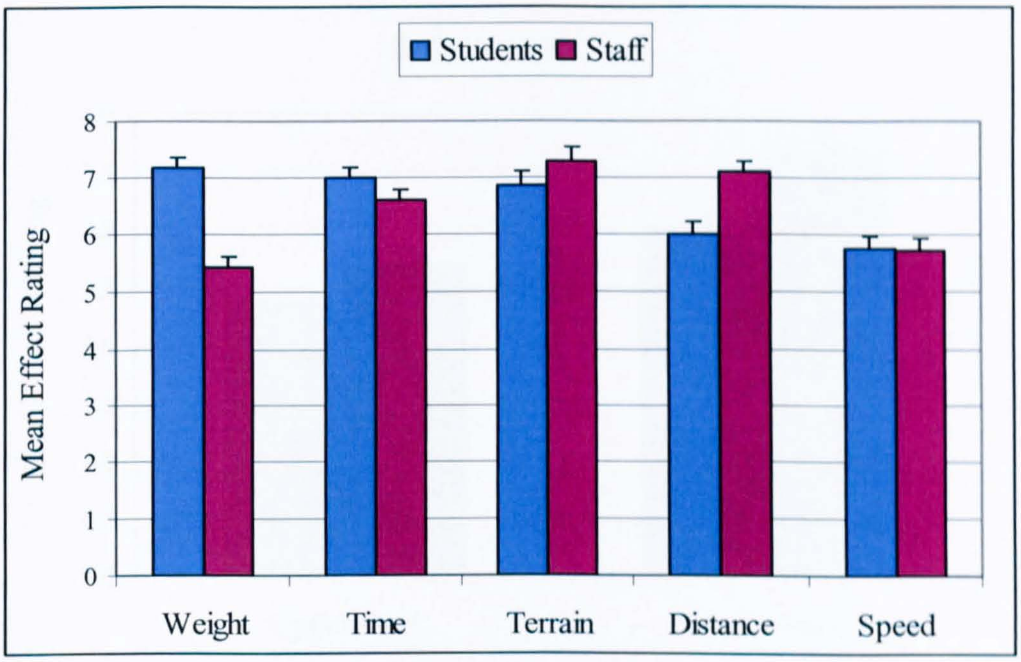


Figure 11.16: Mean ratings as to which aspect of load carriage most increased general discomfort between students and staff, error bars represent standard error.

The staff questioned also rated the regions of the back as more uncomfortable than the students, at 3.7 verses 3.0 out of 5 respectively. This is more pronounced when considering the lower back (figure 11.17). This is in line with other studies and review articles which suggest lower back complaints are a considerable issue, both in terms of compensation paid, lost work days and injury (Knapik et al, 1992, 1997a & 2004; Songer and LaPorte, 2000). In addition to the higher discomfort ratings given for the back, 78% of staff were concerned with the long-term implications that carrying loads would have on their back. This is in contrast to only 34% of students stating a concern. The overall increase in staff concern regarding the back is not surprising. In the context of this thesis staff are regarded as experienced load carriers, with many of the staff ex-military. Chapter 8 of this thesis (section 8.4.1) highlighted back pain as a long-term load carriage injury, this was also recognised by Knapik et al, 2004. Research conducted for this chapter suggests that back discomfort, and injury (discussed in the following section), occurs in both experienced and inexperienced load carriers. However, experienced load carriers sustain increased discomfort and injury rates.

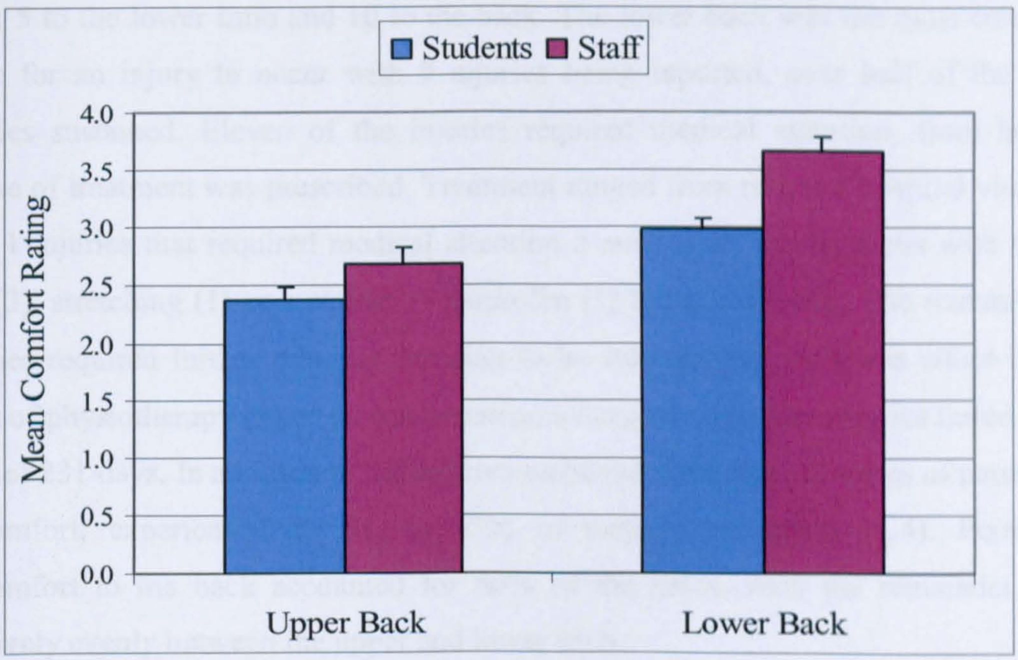


Figure 11.17: Mean comfort rating for the back as given by students and staff, error bars represent standard error.

The staff also rated the shoulder as more uncomfortable than the students questioned, the neck and hands received similar responses (table 11.3). In addition to this 67% of staff stated a concern of the long-term implications that load carriage has on their upper limb. This is compared to only 17% of students. Regarding blisters only 20% of staff typically experience blisters when marching with loads. This low number may be as a result of boots being worn in, or adaptations to the foot occurring, or simply experience in methods of reducing blister formation.

11.4.4 Results Regarding Injuries

Of considerable interest to this thesis were the incidence and prevalence of load carriage related injuries. These data were collected with the current questionnaire by asking participants to recollect any discomfort or medical visit they have experienced. Injuries and persistent discomfort were recorded.

There were a total of 17 injuries reported by different students, this accounts for approximately 20% of the participants who completed the questionnaire (table 11.5). At this point it is again worth pointing out that participants were asked to recollect any period of load carriage they had conducted, with particular emphasis on the summer exercises 10 weeks previously. Of these 17 injuries 2 were to the upper limb, 5 to the lower limb and 10 to the back. The lower back was the most common place for an injury to occur with 9 injuries being reported, over half of the total injuries sustained. Eleven of the injuries required medical attention, from here a course of treatment was prescribed. Treatment ranged from rest to a hospital visit. Of the 11 injuries that required medical attention 5 needed no further visits with either rest (3), stretching (1) or a course of ibuprofen (1) being sufficient. The remaining 6 injuries required further medical attention to be administered, this was either in the form of physiotherapy (5) or on one occasion a hospital visit. The injuries lasted for a total of 231 days. In addition to the injuries sustained there were 67 cases of persistent discomfort, experienced by 51, or 57% of participants (table 11.4). Persistent discomfort to the back accounted for 46% of the cases, with the remainder split relatively evenly between the upper and lower limb.

Relating the findings from this study to those in the literature can be achieved, again it is worth noting that this group of participants were not full-time soldiers. Reynolds et al (1999) found a total of 36% of soldiers completing 5 consecutive days of 20 km road marching with load suffered one or more injuries, with 8% of soldiers unable to complete the exercise due to injury. Knapik et al (1992) recorded injury rates following a 20 km strenuous road march. A total of 24% of soldiers sustained one or more injury, with half of these requiring medical attention. The second most common injury, behind blisters, were back complaints accounting for 20% of injuries. Twelve soldiers could not complete the march, of these 6 were attributed to back pain.

This study suggests that for young part-time military trainees load carriage related injuries affect 20% of participants. With injury to the lower back accounting for over half of the injuries sustained. Although an injury rate of 20% is lower than in the literature above, these studies counted blisters in with the number of injuries. For this study it was deemed too inaccurate to attempt to determine actual blister rates, as the questionnaire was distributed around 10 weeks after a specific load carriage exercise. For this reason it was left out of the injury analysis, but typical blister rates were reported previously. Persistent discomfort as a result of load carriage affected 57% of participants, with the back again accounting for just under half of these.

The main point of interest regarding injury to the staff that completed the questionnaire was that 78% had suffered persistent discomfort in the back region. This may account for the high rating given for back discomfort during load carriage in section 11.4.3. Of these who experienced back discomfort two had to visit a medical professional, with one case requiring further medical attention from a physiotherapist. Results show that half of the staff reported at least one injury, with 6 injuries in total. Two injuries each to the upper limb, back and lower limb.

11.5 Conclusion

The lower back was rated as the most uncomfortable region of the body following a typical period of load carriage for both the student and staff groups of participants. However, the staff rated the lower back as more uncomfortable than the students. The shoulders were the second with both groups. Females reported both the upper and lower back as significantly more uncomfortable during typical load carriage than the males. The same was also true for the knee and the neck. More student participants are concerned about the long-term implications of load carriage on their backs than the upper limb. Almost half of participants typically experience blisters when undertaking military activities, with the heel the most common place for blister formation. Two-thirds of participants felt that load carriage reduces their ability to perform a physical task at the end of a march. This chapter suggests that in order to minimise discomfort as a result of load carriage a training exercise should not include all 3 of the following conditions simultaneously; heavy loads, long durations and difficult gradient or terrain. These 3 factors were rated as most significantly increasing general and upper limb discomfort during load carriage exercises. Females rated speed as significantly increasing discomfort during load carriage compared to males; this may be as a result of their shorter stride lengths.

Of interest to this thesis were the incidence and prevalence of load carriage related injuries. Approximately 20% of student participants reported at least one injury of any sort. The most common site for a load carriage related injury was the lower back, accounting for 53% of the injuries sustained. There were also 67 cases of persistent discomfort, experienced by 57% of participants, accounting for just under half of these discomforts was the lower back.

11.6 Limitations

Unlike other studies presented in this thesis, comfort ratings for this study were not taken during or immediately following a period of load carriage, the data collected here is retrospective. This does create potential inaccuracies with the data as a time lag was present between completing the questionnaire and the actual load carrying exercise. Annett (2002) suggested that the preferred method is to collect subjective responses during testing, if minimal interruption to the testing procedure is achieved. However, the aim of the questionnaire distributed for this study was to assess the participant's general feeling towards load carriage, drawing on their previous experiences of carrying loads. The summer exercises that all participants completed were a point of reference to focus and enhance their recollection of how they typically feel after and during load carriage. They also acted as a specific event from which injury data could be collected. Although participants were of a relatively young age (17 – 18), they all had previous experience of military load carriage. The population selected for this study, although young, are representative subsection of the military. This being new recruits with minimal operational experience. In comparison to other studies conducted for this thesis the participant age is slightly younger, but comparable. For example, with this study the average age of participants was 17.5 years, in chapter 9 the average age for the interview group was 19 years, and chapter 10 the average age of participants in 'B' company was 20 years. The notion with the current questionnaire study was data from young load carriers could be compared to older and more experienced load carriers. This would highlight issues which are of importance to younger trainees, and how their perception of load carriage differs. As reported widely within the media the British armed forces is currently experiencing a short-fall in recruitment. This combined with anecdotal evidence collected while researching this thesis from members of the military, suggest that the retention of young recruits is of importance to correct, or slow, this short-fall. The author also suggests that addressing issues relating to young military personnel may play a vital role in reducing the long-term injuries sustained by career soldiers.

Chapter Twelve – Summary and Future Work

12.1 Introduction

This final chapter of the thesis will draw together all the conclusions from the work presented thus far. It will also outline potential future research work, and conclude with a final comment.

12.2 Summary

The objectives of the thesis were:

1. Evaluate the effects that load carriage has on the biomechanics of human gait.
2. Determine the incidence and prevalence of load carriage related discomfort and injuries within the military.
3. Establish and appraise biomechanical risk factors for injury.

Aspects of load carriage research have been experimentally tested which do not appear, to the author's knowledge, in the published scientific literature. This includes reviewing the effect of rifle carriage on the kinetics of human gait, and conducting an in-depth 3D, bi-lateral gait analysis of load carriage. In addition, this thesis has benchmarked the kinetic effects of load carriage using UK standard issue '90 pattern load carriage systems (LCS) and AirMesh IV prototype LCS.

Reviewing load carriage discomfort has been possible and investigated extensively for this thesis. Important issues regarding early development of pain, regions specifically at risk and gender differences were identified. The thesis also determined the incidence and prevalence of load carriage related injuries within young, operationally inexperienced military trainees. The lower back was highlighted as the region where the greatest number of injuries and persistent discomforts were identified.

The final aim of the thesis was always expected to be the most difficult to achieve. Proven relationships between biomechanical changes, as a direct result of load carriage, and injury have not been established in the literature. However, certain theoretical risk factors have been established and some of these do alter with load carriage, these include:

1. Increases in vertical ground reaction forces, in particular at heel strike, have been shown to increase the risk of developing overuse injuries. Results from this study showed that the impact peak increases proportionally with increasing carried load. This will increase the risk of developing overuse injuries in the lower limb when marching with loads.
2. Increases to peak anteroposterior forces increase the risk of blister formation, due to increased shearing forces. Again this study showed that these forces increase proportionally to carried load. In addition to this carrying load in a backpack significantly increases maximum braking force compared to a double-pack. Again increasing the risk of blister formation.
3. Using regression analysis chapter 4 generated an equation to predict the increase in impact peak at heel strike. This tool may be useful as with additional information it may become possible to predict the number of stress factures that will occur with a march of known distance. Alternatively, it could be used to set limits to distances walked and loads carried until such time that an increase in bone mineral density has occurred.
4. Rifle carriage increased impact peak and mediolateral forces independent of load carriage. As stated above this may increase the risk of developing overuse injuries in the lower limb.
5. Peak and mean external knee rotation moments increased proportionally with the addition of load. The peak moment occurred just after heel strike and may increase the risk of acute or overuse knee injuries due to continual loading.
6. Pelvic tilt increased with load. The typical measure of forward lean is from the hip to either the C7 or shoulder. Forward lean has been shown to increase stress placed on the back and neck muscles. It is suggested by this thesis that if forward lean cannot be measured then pelvic tilt is a suitable substitute.

12.3 Limitations of Thesis

An original aim of the thesis was to determine the incidence and prevalence of load carriage related injuries within the military. Due to significant issues out of the author's control it was not possible to determine injury rates for the wider military population. These issues included: Restricted access to full-time soldiers; confidentially issues regarding the reviewing of medical records; MoD stopping project funding only half way through the project; and a general unwillingness for persons outside of the military to assess sensitive injury records. The thesis did however manage to determine injury rates for young military trainees at a Defence 6th form college. Despite this difficultly in obtaining military participants it was deemed important that the injury and discomfort investigations were conducted with military personnel. This was achieved with chapters 9 through 11 utilising full-time soldiers, members of the East Midlands Officer Training Corps and students and staff at Welbeck Defence College.

Participants used for the biomechanical studies were not recruited from military organisations, they were recruited from Loughborough University. Inclusion criteria for participation in these studies were that participants were physically fit and had experience carrying heavy loads. Approximately half of all participants recruited were either current part-time soldiers or previous full-time soldiers. The remainder consisted of experienced hikers, walkers and backpackers. The participants selected for the biomechanical studies ensured that representative gait cycles were obtained.

It is the belief of the author that correct and appropriate methodologies were used throughout the thesis. The questionnaire employed to collect load carriage discomfort data in chapter 9 was improved following feedback, and from reviewing the results gleaned from the data. This improved questionnaire was then distributed in an edited form in chapter 11. Limitations with the first questionnaire were highlighted in chapter 9. Chapter 10 attempted to determine injury incidence following a 1 hour field march with load. No injuries were reported to the on-site medical professional, leading to the conclusion that 1 hour of load carriage was not sufficient to cause injury or severe discomfort. Future work should consider a longer period of load carriage. There are also considerations to be had regarding the use of questionnaires, as data is self reported and often relies on memory recall. Annett (2002) suggest the preferred method is to collect subjective responses during testing, if minimal interruption to the testing procedure is achieved. This eliminates the need for memory recall. However, this thesis has highlighted issues with questioning immediately after or during an exercise, as potential important information may not be collected or missed. Self reporting is also another place for potential errors. However, a well written, constructed and piloted questionnaire will minimise these inaccuracies.

With the biomechanical studies well established methodologies of gait analysis were used. A useful addition to the analysis would have been the assessment of the body's centre of mass. Carrying loads changes the centre of mass and may be attributed to some of the biomechanical change observed within this thesis. Despite observations regarding the centre of mass being made by the author, actual measurements of change would be beneficial to help quantify the changes observed. Measurements of the changes to the body's centre of mass are rare within the pertinent literature, due to the difficulty of its measurement.

12.4 Future Work

While conducting work for this thesis numerous areas for future work have been highlighted, these include:

1. Further investigation is needed into the effect of rifle carriage in the military. This includes investigating the physiological cost and further biomechanical analysis.
2. An intervention study investigating the effect of gradually increasing either the load carried or distance carried and its effects on injury rates with military trainees. Research may be able to set limits of load carriage during initial training to reduce injury and dropout rates.
3. This thesis conducted the first 3D, bi-lateral gait analysis of load carriage. Therefore future research is needed to corroborate or reject these findings.
4. Changing the design of future load carriage systems may increase comfort of the user. Increased comfort has been shown in this thesis to reduce severe pain or non-completion and increase cognitive ability.
5. Young military trainees will have different injuries and injury rates compared to experienced soldiers. Research is needed to compare these two groups.

6. The final and potentially most important area for future research will be one which links the subjective comfort ratings across biomechanical and injury data. Thus closing the gap in knowledge between biomechanics and injury.

12.5 Final Comment

The research conducted for this thesis has shown that load carriage changes basal gait patterns; these induced changes can increase injury risk. It has been discussed how these changes could increase injury risk. In addition, load carriage causes inevitable discomfort particularly to the shoulders and lower back. Biomechanical indicators for injury prediction have been put forward by this thesis and future work should focus on trying to establish these principles.

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Appendices

Appendix 3.1: Example participant information sheet, health screen questionnaire and consent form.

The Effect of Carrying Military Loads on Selected GRF Parameters

PARTICIPANT INFORMATION SHEET

The purpose of this study is to investigate the effects military loads have on selected GRF parameters. The study will also look at the effects that restricted arm movements (induced by carrying a replica rifle), and different distributions of load have on GRFs. Results from this study will hopefully aid in the development of load carriage systems (LCS) and help with load carriage injury assessment.

During the study you will be asked to walk at a controlled speed for 8 conditions. LCS refers to Webbing, Backpack and carrying a replica rifle:

1. Control – Wearing non-restrictive clothes and a pair of military boots.
2. Rifle – As above but carrying a replica rifle.
3. Webbing 1 – As above with the addition of Webbing weighing 8 kg.
4. Webbing 2 – Increasing Webbing weight to 16 kg.
5. Backpack – Substituting Webbing for a Backpack loaded with 16 kg.
6. LCS 1 – Carrying 8 kg Webbing and 16 kg Backpack.
7. LCS 2 – Carrying 16 kg Webbing and 16 kg Backpack.
8. LCS 3 – As above but with the addition of an 8 kg load.

In order for measurement to be taken you will be asked to walk at a controlled speed along a 10 m walkway with a force plate in the centre. The force plate measures the GRFs produced during walking and software stores the raw data for later analysis. Video recording or digital photographs may be taken, this allows further analysis and may be used for presentations, your identity will be kept confidential al all times.

Each testing session will consist of up to 8 conditions, with 10 successful repeat trials per condition. Before each condition a period of adjustment will be given for you to get used to the load and adjust your starting position so the force plate is struck cleanly. Each condition should take between 5 and 10 minutes, with a total time of between 1 and 1 ½ hours. Rest will be given if needed between the heavy load trials.

In order to minimise the risks from load carriage you will be asked to complete a health screen questionnaire. If you suffer from musculoskeletal or gait discomfort or disorders you will not be able to participate. Likewise you will not be able to participate if you suffer from diagnosed respiratory, circulatory or blood pressure difficulties or are receiving medication.

Any load carriage may include some discomfort at the interface between the pack and body. It should not be excessive but you are entitled to withdraw from the study at any time for any reason, and you will not be required to explain your reasoning. You also have the right to remove your data after the study is complete. Please feel free to ask questions at any time.

Thank you for your participation.

The Effect of Carrying Military Loads on Selected GRF Parameters

HEALTH SCREEN QUESTIONNAIRE

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:
   - (a) On medication, prescribed or otherwise............................ Yes ☐ No ☐
   - (b) Attending your general practitioner .... Yes ☐ No ☐
   - (c) On a hospital waiting list .... Yes ☐ No ☐
2. **At present,** do you have any of the following health problems or are you receiving treatment for:
   - (a) Back and/or shoulder pain.. Yes ☐ No ☐
   - (b) Knee and/or foot injuries.. Yes ☐ No ☐
   - (c) Any other muscle injuries .... Yes ☐ No ☐
3. **In the past two years,** have you had any illness which require you to:
   - (a) Any serious injuries or illnesses that have caused you to attend a hospital or hospital outpatient department.................... Yes ☐ No ☐
4. **Have you ever** had any of the following:
   - (a) Pathological/atypical gait patterns.................................... Yes ☐ No ☐
   - (b) Surgery that altered your gait pattern................................ Yes ☐ No ☐
   - (c) Problems with bones or joints .... Yes ☐ No ☐
   - (d) Disturbance of balance/coordination................................. Yes ☐ No ☐
   - (e) Numbness in hands or feet... Yes ☐ No ☐

(f) Disturbance of vision .... Yes ☐ No ☐

(g) Convulsions/epilepsy .... Yes ☐ No ☐

(h) Heart, circulation and/or respiratory problems.................. Yes ☐ No ☐

4. **Do you** consider yourself to being in good health at present? Yes ☐ No ☐

If YES to any question (or "NO" to question 4), please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.)

....

....

....

Thank you for your cooperation!

The Effect of Carrying Military Loads on Selected GRF Parameters

INFORMED CONSENT

I .... have read the information sheet concerning

the load carriage experiment and been given the opportunity to ask for clarification

and further details. I understand the conditions I shall experience in the trials and

what is required of me.

I freely give my consent to take part in this study. I understand I am free to withdraw at any time, without explanation if I prefer.

Do you give permission for video or photographs to be taken during to study, these may be used for further analysis or for presentation purposes. Identity will be kept confidential and you will be informed if your images are to be used. You may still take part in the study if you tick 'No'.

Yes ☐ No ☐

Signed : .... Date : ....

Print name : ....

Appendix 7.1(a): Results showing mean data for the hip moments measured, standard deviation in parenthesis. * indicated significant main effect of load. Proceeding 2 pages show data for the knee and ankle moments.

Movement	Parameter	Condition					Level of Significance	Bonferroni Significance
		Rifle	8 kg	16 kg	24 kg	32 kg		
Hip Abductor	Maximum	1.271 (0.25)	1.429 (0.26)	1.552 (0.28)	1.623 (0.31)	1.768 (0.33)	$p < 0.001$ *	Yes
	Minimum	-0.257 (0.14)	-0.280 (0.13)	-0.275 (0.13)	-0.298 (0.15)	-0.301 (0.14)	NS	No
	Mean (+ve)	0.449 (0.09)	0.500 (0.10)	0.544 (0.11)	0.591 (0.12)	0.654 (0.11)	$p < 0.001$ *	Yes
	Mean (-ve)	0.021 (0.02)	0.020 (0.01)	0.021 (0.02)	0.022 (0.02)	0.022 (0.02)	NS	No
	Mean	0.561 (0.11)	0.623 (0.11)	0.674 (0.13)	0.726 (0.13)	0.805 (0.12)	$p < 0.001$ *	Yes
Hip Extensor	Maximum	2.118 (0.94)	2.292 (1.06)	2.391 (1.05)	2.466 (1.18)	2.839 (1.24)	$p < 0.001$ *	Yes
	Minimum	-0.964 (0.34)	-1.061 (0.40)	-1.129 (0.46)	-1.161 (0.46)	-1.226 (0.51)	$p < 0.001$ *	Yes
	Mean (+ve)	0.236 (0.12)	0.244 (0.13)	0.268 (0.17)	0.280 (0.18)	0.294 (0.16)	NS	No
	Mean (-ve)	-0.164 (0.06)	-0.190 (0.08)	-0.209 (0.08)	-0.220 (0.10)	-0.245 (0.10)	$p < 0.001$ *	Yes
	Mean	0.103 (0.20)	0.085 (0.24)	0.112 (0.33)	0.107 (0.36)	0.092 (0.32)	NS	No
Hip Rotator	Maximum	0.272 (0.14)	0.305 (0.15)	0.357 (0.18)	0.365 (0.13)	0.394 (0.16)	$p < 0.001$ *	Yes
	Minimum	-0.100 (0.04)	-0.108 (0.04)	-0.108 (0.04)	-0.155 (0.06)	-0.133 (0.07)	$p < 0.05$ *	No
	Mean (+ve)	0.044 (0.02)	0.050 (0.03)	0.062 (0.03)	0.067 (0.03)	0.076 (0.04)	$p < 0.001$ *	Yes
	Mean (-ve)	-0.017 (0.01)	-0.019 (0.01)	-0.019 (0.01)	-0.020 (0.01)	-0.023 (0.02)	NS	No
	Mean	0.035 (0.03)	0.041 (0.04)	0.057 (0.04)	0.061 (0.04)	0.067 (0.04)	$p < 0.001$ *	Yes

Appendix 7.1(b): Results showing mean data for the knee moments measured, standard deviation in parenthesis. * indicated significant main effect of load.

Movement	Parameter	Condition					Level of	Bonferroni
		Rifle	8 kg	16 kg	24 kg	32 kg	Significance	Significance
Knee Valgus	Maximum	0.545 (0.15)	0.597 (0.18)	0.622 (0.15)	0.665 (0.17)	0.813 (0.23)	$p < 0.001$ *	Yes
	Minimum	-0.140 (0.04)	-0.139 (0.04)	-0.161 (0.06)	-0.171 (0.06)	0.174 (0.07)	$p < 0.01$ *	No
	Mean (+ve)	0.167 (0.05)	0.186 (0.05)	0.197 (0.07)	0.212 (0.07)	0.229 (0.08)	$p < 0.001$ *	Yes
	Mean (-ve)	0.010 (0.01)	0.010 (0.01)	0.011 (0.01)	0.011 (0.01)	0.012 (0.01)	NS	No
	Mean	0.204 (0.06)	0.227 (0.07)	0.238 (0.09)	0.255 (0.10)	0.276 (0.11)	$p < 0.01$ *	Yes
Knee Extensor	Maximum	0.954 (0.37)	1.062 (0.37)	1.253 (0.41)	1.353 (0.34)	1.495 (0.45)	$p < 0.001$ *	Yes
	Minimum	-0.936 (0.38)	-1.019 (0.42)	-1.056 (0.40)	-1.086 (0.49)	-1.223 (0.47)	$p < 0.001$ *	Yes
	Mean (+ve)	0.184 (0.08)	0.213 (0.09)	0.251 (0.09)	0.294 (0.11)	0.340 (0.13)	$p < 0.001$ *	Yes
	Mean (-ve)	-0.040 (0.02)	-0.044 (0.02)	-0.046 (0.02)	-0.046 (0.03)	-0.050 (0.03)	NS	No
	Mean	0.183 (0.10)	0.212 (0.13)	0.256 (0.12)	0.308 (0.14)	0.361 (0.17)	$p < 0.001$ *	Yes
Knee Rotator	Maximum	0.158 (0.05)	0.177 (0.05)	0.183 (0.06)	0.199 (0.07)	0.208 (0.08)	$p < 0.001$ *	Yes
	Minimum	-0.031 (0.02)	-0.033 (0.02)	-0.037 (0.02)	-0.038 (0.02)	-0.048 (0.02)	$p < 0.001$ *	Yes
	Mean (+ve)	0.043 (0.01)	0.048 (0.02)	0.050 (0.02)	0.056 (0.02)	0.059 (0.02)	$p < 0.001$ *	Yes
	Mean (-ve)	$9.5E^{-4}$ (4.9^{-4})	$1.0E^{-3}$ (4.7^{-4})	$1.1E^{-3}$ (5.8^{-4})	$1.1E^{-3}$ (6.4^{-4})	$1.4E^{-3}$ (6.6^{-4})	$p < 0.001$ *	Yes
	Mean	0.055 (0.02)	0.060 (0.02)	0.063 (0.02)	0.070 (0.03)	0.073 (0.03)	$p < 0.001$ *	Yes

Appendix 7.1(c): Results showing mean data for the ankle moments measured, standard deviation in parenthesis. * indicated significant main effect of load.

Movement	Parameter	Condition					Level of	Bonferroni
		Rifle	8 kg	16 kg	24 kg	32 kg	Significance	Significance
Ankle Pronator	Maximum	0.514 (0.12)	0.546 (0.13)	0.578 (0.16)	0.608 (0.17)	0.659 (0.18)	$p < 0.001$ *	Yes
	Minimum	-0.007 (0.01)	-0.008 (0.01)	-0.008 (0.01)	-0.007 (0.01)	-0.008 (0.01)	NS	No
	Mean (+ve)	0.159 (0.05)	0.174 (0.06)	0.186 (0.07)	0.200 (0.07)	0.220 (0.07)	$p < 0.001$ *	Yes
	Mean (-ve)	$1.4E^{-4}$ (2.2^{-4})	$1.8E^{-4}$ (2.9^{-4})	$1.2E^{-4}$ (1.8^{-4})	$1.7E^{-4}$ (4.2^{-4})	$1.3E^{-4}$ (1.9^{-4})	NS	No
	Mean	0.205 (0.06)	0.222 (0.07)	0.239 (0.08)	0.253 (0.08)	0.276 (0.09)	$p < 0.001$ *	Yes
Ankle Planterflexor	Maximum	1.714 (0.07)	1.869 (0.05)	1.947 (0.09)	2.091 (0.09)	2.154 (0.13)	$p < 0.001$ *	Yes
	Minimum	0.232 (0.09)	0.230 (0.09)	0.239 (0.09)	0.242 (0.09)	0.279 (0.10)	$p < 0.001$ *	Yes
	Mean (+ve)	0.491 (0.11)	0.543 (0.13)	0.576 (0.13)	0.626 (0.14)	0.650 (0.16)	$p < 0.001$ *	Yes
	Mean (-ve)	-0.016 (0.01)	-0.015 (0.01)	-0.015 (0.01)	-0.015 (0.01)	-0.018 (0.01)	NS	No
	Mean	0.614 (0.14)	0.677 (0.15)	0.717 (0.16)	0.774 (0.16)	0.796 (0.18)	$p < 0.001$ *	Yes
Ankle Alignment	Maximum	0.038 (0.02)	0.039 (0.02)	0.053 (0.03)	0.053 (0.03)	0.064 (0.04)	$p < 0.01$ *	No
	Minimum	-0.263 (0.14)	-0.294 (0.14)	-0.294 (0.17)	-0.324 (0.18)	-0.357 (0.18)	$p < 0.01$ *	Yes
	Mean (+ve)	$2.3E^{-4}$ (9.7^{-4})	$2.3E^{-4}$ (1.3^{-4})	$3.5E^{-4}$ (2.4^{-4})	$3.9E^{-4}$ (3.2^{-4})	$4.0E^{-4}$ (3.3^{-4})	NS	No
	Mean (-ve)	-0.072 (0.04)	-0.081 (0.05)	-0.080 (0.05)	-0.088 (0.05)	-0.094 (0.05)	$p < 0.05$ *	No
	Mean	-0.091 (0.05)	-0.102 (0.06)	-0.097 (0.06)	-0.106 (0.07)	0.112 (0.06)	NS	No

Appendix 7.2(a): Results showing mean data for the hip power measured, standard deviation in parenthesis. * indicated significant main effect of load. Proceeding 2 pages show data for the knee and ankle power.

Movement	Parameter	Condition					Level of	Bonferroni
		Rifle	8 kg	16 kg	24 kg	32 kg	Significance	Significance
Hip Abductor	Maximum	0.704 (0.22)	0.630 (0.20)	0.706 (0.28)	0.810 (0.41)	1.104 (0.67)	$p < 0.05$ *	No
	Minimum	-0.898 (0.31)	-1.000 (0.38)	-1.013 (0.33)	-1.146 (0.40)	-1.258 (0.41)	$p < 0.05$ *	No
	Mean (+ve)	0.077 (0.03)	0.078 (0.03)	0.082 (0.04)	0.111 (0.07)	0.149 (0.09)	$p < 0.01$ *	Yes
	Mean (-ve)	-0.110 (0.04)	-0.124 (0.05)	-0.129 (0.04)	-0.150 (0.06)	-0.165 (0.05)	$p < 0.001$ *	Yes
	Mean	-0.042 (0.08)	-0.062 (0.08)	-0.062 (0.08)	-0.049 (0.12)	-0.027 (0.12)	NS	No
Hip Extensor	Maximum	1.479 (0.44)	1.532 (0.45)	1.661 (0.65)	1.788 (0.64)	1.909 (0.72)	$p < 0.05$ *	No
	Minimum	-1.113 (0.38)	-1.328 (0.42)	-1.453 (0.54)	-1.462 (0.60)	-1.506 (0.48)	$p < 0.05$ *	No
	Mean (+ve)	0.255 (0.13)	0.253 (0.13)	0.283 (0.18)	0.298 (0.19)	0.299 (0.16)	NS	No
	Mean (-ve)	-0.151 (0.07)	-0.178 (0.09)	-0.203 (0.10)	-0.213 (0.12)	-0.249 (0.11)	$p < 0.001$ *	Yes
	Mean	0.136 (0.24)	0.098 (0.26)	0.117 (0.34)	0.118 (0.36)	0.083 (0.32)	NS	No
Hip Rotator	Maximum	0.308 (0.17)	0.370 (0.25)	0.494 (0.30)	0.480 (0.29)	0.533 (0.31)	$p < 0.001$ *	Yes
	Minimum	-0.229 (0.13)	-0.231 (0.11)	-0.311 (0.18)	-0.380 (0.20)	-0.499 (0.25)	$p < 0.001$ *	Yes
	Mean (+ve)	0.023 (0.01)	0.029 (0.02)	0.036 (0.02)	0.034 (0.02)	0.037 (0.02)	$p < 0.05$ *	No
	Mean (-ve)	-0.016 (0.01)	-0.019 (0.01)	-0.025 (0.01)	-0.033 (0.02)	-0.046 (0.02)	$p < 0.001$ *	Yes
	Mean	0.009 (0.02)	0.012 (0.02)	0.014 (0.02)	0.001 (0.02)	-0.017 (0.03)	$p < 0.001$ *	Yes

Appendix 7.2(b): Results showing mean data for the knee power measured, standard deviation in parenthesis. * indicated significant main effect of load.

Movement	Parameter	Condition					Level of Significance	Bonferroni Significance
		Rifle	8 kg	16 kg	24 kg	32 kg		
Knee Valgus	Maximum	0.309 (0.17)	0.376 (0.17)	0.400 (0.20)	0.462 (0.27)	0.579 (0.27)	$p < 0.001$ *	Yes
	Minimum	-0.225 (0.11)	-0.258 (0.14)	-0.283 (0.13)	-0.336 (0.22)	-0.499 (0.38)	$p = 0.032$ *	No
	Mean (+ve)	0.029 (0.02)	0.039 (0.03)	0.039 (0.02)	0.048 (0.03)	0.056 (0.03)	$p = 0.005$ *	Yes
	Mean (-ve)	-0.024 (0.01)	-0.029 (0.01)	-0.032 (0.01)	-0.035 (0.01)	-0.041 (0.02)	$p < 0.001$ *	Yes
	Mean	0.001 (0.01)	0.005 (0.01)	0.002 (0.02)	-0.001 (0.02)	-0.002 (0.02)	NS	No
Knee Extensor	Maximum	2.696 (1.30)	2.926 (1.50)	3.061 (1.71)	2.901 (1.33)	3.345 (1.61)	$p < 0.01$ *	No
	Minimum	-2.156 (0.80)	-2.265 (0.71)	-2.784 (0.89)	-2.879 (0.66)	-3.277 (0.96)	$p < 0.001$ *	Yes
	Mean (+ve)	0.141 (0.06)	0.158 (0.06)	0.182 (0.07)	0.210 (0.08)	0.244 (0.10)	$p < 0.001$ *	Yes
	Mean (-ve)	-0.256 (0.09)	-0.293 (0.09)	-0.341 (0.09)	-0.369 (0.10)	-0.434 (0.10)	$p < 0.001$ *	Yes
	Mean	-0.144 (0.08)	-0.169 (0.10)	-0.196 (0.09)	-0.206 (0.11)	-0.222 (0.13)	$p < 0.01$ *	No
Knee Rotator	Maximum	0.108 (0.10)	0.127 (0.11)	0.139 (0.11)	0.143 (0.12)	0.162 (0.12)	NS	No
	Minimum	-0.134 (0.07)	-0.154 (0.10)	-0.164 (0.11)	-0.178 (0.12)	-0.227 (0.16)	$p < 0.05$ *	No
	Mean (+ve)	0.010 (0.01)	0.011 (0.01)	0.013 (0.01)	0.014 (0.01)	0.016 (0.01)	$p < 0.05$ *	No
	Mean (-ve)	-0.014 (0.01)	-0.014 (0.01)	-0.016 (0.01)	-0.017 (0.01)	-0.021 (0.01)	NS	No
	Mean	0.007 (0.01)	0.009 (0.01)	0.008 (0.01)	0.009 (0.01)	0.012 (0.01)	NS	No

Appendix 7.2(c): Results showing mean data for the ankle power measured, standard deviation in parenthesis. * indicated significant main effect of load.

Movement	Parameter	Condition					Level of Significance	Bonferroni Significance
		Rifle	8 kg	16 kg	24 kg	32 kg		
Ankle Pronator	Maximum	0.241 (0.07)	0.214 (0.10)	0.303 (0.19)	0.305 (0.19)	0.410 (0.19)	$p < 0.01$ *	No
	Minimum	-0.386 (0.11)	-0.438 (0.18)	-0.425 (0.21)	-0.465 (0.30)	-0.578 (0.31)	NS	No
	Mean (+ve)	0.023 (0.01)	0.023 (0.01)	0.028 (0.02)	0.029 (0.01)	0.036 (0.01)	$p < 0.01$ *	Yes
	Mean (-ve)	-0.047 (0.01)	-0.050 (0.02)	-0.051 (0.03)	-0.052 (0.03)	-0.065 (0.02)	$p < 0.01$ *	Yes
	Mean	-0.032 (0.02)	-0.035 (0.02)	-0.028 (0.03)	-0.030 (0.03)	-0.037 (0.03)	NS	No
Ankle Planterflexor	Maximum	2.994 (0.54)	3.375 (0.63)	3.558 (0.83)	3.755 (0.83)	4.172 (1.02)	$p < 0.001$ *	Yes
	Minimum	-0.918 (0.22)	-1.056 (0.29)	-1.034 (0.34)	-1.044 (0.31)	-1.156 (0.30)	$p < 0.01$ *	Yes
	Mean (+ve)	0.292 (0.07)	0.327 (0.08)	0.366 (0.10)	0.392 (0.11)	0.441 (0.14)	$p < 0.001$ *	Yes
	Mean (-ve)	-0.185 (0.05)	-0.214 (0.06)	-0.207 (0.07)	-0.212 (0.07)	-0.239 (0.07)	$p < 0.001$ *	Yes
	Mean	0.142 (0.08)	0.147 (0.10)	0.207 (0.12)	0.245 (0.12)	0.270 (0.16)	$p < 0.001$ *	Yes
Ankle Alignment	Maximum	0.207 (0.12)	0.246 (0.25)	0.246 (0.25)	0.282 (0.28)	0.367 (0.37)	$p < 0.01$ *	No
	Minimum	-0.095 (0.06)	-0.099 (0.06)	-0.102 (0.09)	-0.108 (0.08)	-0.201 (0.18)	$p < 0.05$ *	No
	Mean (+ve)	0.021 (0.01)	0.025 (0.01)	0.025 (0.01)	0.027 (0.02)	0.035 (0.02)	$p < 0.05$ *	No
	Mean (-ve)	-0.009 (0.01)	-0.011 (0.01)	-0.012 (0.01)	-0.013 (0.01)	-0.018 (0.01)	$p < 0.05$ *	No
	Mean	0.017 (0.01)	0.020 (0.01)	0.020 (0.01)	0.021 (0.02)	0.026 (0.02)	$p < 0.05$ *	No

Appendix 7.3: Results showing mean RoM data for the 12 kinematic parameters measured, standard deviation in parenthesis. * indicated significant main effect of load.

Joint	**Movement**	**Condition**					**Level of Significance**
		Rifle	8 kg	16 kg	24 kg	32 kg	
Ankle	Dorsiflexion/Planterflexion	23.43 (3.2)	23.52 (2.6)	24.32 (2.7)	24.53 (2.2)	24.17 (3.4)	NS
	Pronation/Supination	8.58 (1.7)	8.77 (1.8)	8.91 (1.9)	9.21 (2.1)	9.08 (1.4)	NS
	Alignment	10.97 (2.7)	11.58 (2.7)	11.96 (2.5)	12.09 (2.6)	11.92 (3.0)	NS
Knee	Flexion/Extension	66.58 (1.9)	66.68 (1.9)	66.62 (1.9)	65.38 (2.1)	64.23 (1.6)	$p < 0.05$ *
	Valgus/Varus	10.27 (3.7)	10.71 (4.0)	10.69 (3.9)	11.00 (3.5)	11.14 (3.5)	NS
	Rotation	13.66 (2.6)	13.56 (3.2)	13.49 (2.8)	13.30 (3.0)	14.54 (4.3)	NS
Hip	Flexion/Extension	46.55 (4.1)	47.38 (4.1)	47.88 (4.3)	47.86 (4.7)	48.35 (3.4)	NS
	Adduction/Abduction	11.00 (1.6)	11.42 (1.8)	12.38 (2.5)	12.96 (2.8)	14.90 (4.7)	$p < 0.05$ *
	Rotation	14.34 (4.0)	13.75 (3.3)	15.36 (4.0)	15.84 (3.2)	18.62 (4.1)	$p < 0.05$ *
Pelvis	Tilt	3.66 (1.2)	3.65 (1.1)	4.74 (2.0)	4.76 (1.4)	5.19 (3.0)	$p < 0.05$ *
	Obliquity	6.13 (1.1)	5.97 (1.3)	6.80 (2.0)	6.83 (1.7)	7.19 (2.3)	NS
	Rotation	10.08 (2.4)	7.63 (2.1)	7.68 (2.4)	7.34 (1.6)	7.63 (2.3)	$p < 0.05$ *

Appendix 7.4: Results showing mean spatiotemporal parameters measured, standard deviation in parenthesis. * indicated significant main effect of load.

Stride Parameter	**Condition**					**Level of Significance**
	Rifle	8 kg	16 kg	24 kg	32 kg	
Stride Time	1.10 (0.03)	1.09 (0.03)	1.10 (0.02)	1.10 (0.02)	1.10 (0.02)	NS
Stride Length	1.68 (0.11)	1.64 (0.10)	1.60 (0.14)	1.57 (0.11)	1.56 (0.12)	$p < 0.05$ *
% Stance	57.90 (1.3)	57.97 (1.7)	58.32 (1.7)	58.52 (1.2)	59.84 (1.1)	$p < 0.05$ *
% Double Support	6.22 (0.8)	6.70 (1.1)	6.93 (1.2)	7.98 (1.4)	10.15 (1.3)	$p < 0.05$ *

Appendix 9.1: Interview questions.

Are you feeling any pain or discomfort?

- If lower limb pain
  - Do you often experience this type of discomfort, if so how often
  - Does it occur while taking part in un-military related activities such as sport or exercise, if so what activity
  - Is the feeling now typical of that while marching
  - Do you think it is aggravated by carrying loads either in a Bergen or webbing
  - Have you had to visit a medical professional due to this or can you manage this discomfort by your self
  - In the past has this type of discomfort caused you to have time off, if yes how many days and on how many separate occasions
  - Does this discomfort restrict your ability to successfully complete your operations, if so how
- If upper limb, neck or back pain
  - Does this type of pain only occur when carrying loads or do you feel it at any other time, if so when
  - Do you regularly feel this type of discomfort when carrying loads either during training or operations, if so how regularly
  - Would you say that the discomfort you are feeling now is increased if you carry a heavier load or with a longer duration of load carriage
  - After the load has been removed how long does the discomfort take to clear and would it restrict your ability for the following days
  - Is this a regular complaint amongst soldiers
  - In your opinion what is the most common injury caused by carrying loads
- What aspect of the 90 Pattern do you feel causes you the most injury.
- How old are your boots and would you consider them to be broken in, through choice would you wear standard issue leather, jungle or commercial boots?
- Have you carried loads with other types of packs before (i.e. commercial packs), if so would you rate these packs as more or less comfortable, have these packs caused you more or less discomfort while carrying loads, what aspect of the pack caused you to feel more or less discomfort.

Appendix 9.2: Example cognitive test, taken from Attwells 2006.

Subject Number Date Time T1

DIGIT	1	2	3	4	5	6	7	8	9
SYMBOL	O	U	⊥	⊐	–	X	Λ	L	=

SCORE

SAMPLES

2	1	3	7	2	4	8	1	5	4	2	1	3	2	1

4	2	3	5	2	3	1	4	6	3	1	5	4	2	7

6	3	5	7	2	8	5	4	6	3	7	2	8	1	9

5	8	4	7	3	6	2	5	1	9	2	8	3	7	4

6	5	9	4	8	3	7	2	6	1	5	4	6	3	7

9	2	8	1	7	9	4	6	8	5	9	7	1	8	5

2	9	4	8	6	3	7	9	8	6

Appendix 9.3: Load carriage injury questionnaire.

The following questionnaire was designed to discover the types of injury or discomfort that are caused by carrying loads in a backpack and/or webbing. All answers will be dealt with in the strictest confidence, so please answer as accurately as possible. For all the questions you must select (by circling) at least one answer but can select as **many** answers as you feel appropriately answer the question. Some of the questions have 'Other' options, if this answer is appropriate please provide as much detail as you can in the space provided.

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

Some Questions will ask you to rate the comfort you felt during the 2 hour trial; the table opposite shows the ratings that should be used. This is the same scale as was used during the trial.

General Questions.

Q1 How long have you been a member of the Military either full/part time or recreational? .... Years .... Months

Q1b Which divisions of the Military have you been a member of?

TA   Officer Training   Cadets   Full Time   Other

....

Q2 How often do you undertake military activities, either training or operations?

Every Day   3+ Days/Week   1-3 Days/Week   Every Few Weeks

Once Month   Few Times Year   Never

Q2b How often do you carry loads, either in backpack and/or webbing during these military activities?

Always   Regularly   Sometimes   Rarely   Never

Upper Limb Injury and/or Discomfort Questions (arms, neck, shoulder, upper back).

Q3 During the current trial did you experience any discomfort to any degree in the upper limb? Yes No

Q3b If yes, which part of the upper limb was this discomfort felt, is this a typical feeling while carrying loads and how uncomfortable would you rate it?

Region	Typical of Carrying Loads	Comfort Rating
Shoulders	Yes / No	
Neck	Yes / No	
Upper Back	Yes / No	
Arms/Hands	Yes / No	

Q4 Which of the following would you say may increase the upper limb discomfort that you felt during the trial or at other times when carrying loads?

Increased Load Increased Time Increased Distance

Increased Speed Other...

Q5 After the load has been removed how quickly does the discomfort disappear?

Straight Away 0-30 Minutes 30-60 Minutes 1-2 Hours

Greater 2 hours Other ....

Lower Limb Injury and/or Discomfort Questions (foot, ankle, knee, hip, legs, importantly not including blisters).

Q6 During the current trial did you experience any discomfort to any degree in the lower limb? Yes No

Q6b If yes, which part of the lower limb was this discomfort felt, is this a typical feeling while carrying loads and how uncomfortable would you rate it?
See table on the next page.

Region	Typical of Carrying Loads	Comfort Rating
Foot	Yes / No	
Ankle	Yes / No	
Knee	Yes / No	
Hips	Yes / No	
Leg	Yes / No	

Q7 Do these feelings of discomfort occur during un-military related activities, such as sport and exercise or every day activities? If yes which activity.

Yes .... No

Blister Injury and/or Discomfort Questions.

Q8 Did you experience blisters during the current trial and is this typical of marching either with or without a load?

Yes No Typical Not typical

Q9 Where on the foot do you most commonly get blisters?

Toes Heel Balls of Feet Sides of Feet

Other ....

Q10 How long do blisters usually take to disappear once marching has stopped?

0-6 Hours 6-24 Hours 1-3 Days 3+ Days

Q11 How would you treat blisters if they did occur?

Clinic Visit Time Off Self-Manageable No Action

Q12 Did you experience 'hot spots' on the foot during the current trial and is this typical when marching either with or without a load?

Yes No Typical Not typical

Q13 Which of the following would you say may increase the discomfort from blisters or heat spots either during the trial or other times when carrying loads?

Increased Load Increased Time Increased Distance

Increased Speed Other..

Questions Regarding the Packs Carried.

Q14 Have you carried loads in (Civi) packs other than the Standard Issue 90 Pattern, if so what make is the pack? Yes .... No

Q14b Which pack do you prefer? 90 Pattern Other Pack No Preference

Q14c What aspect of that pack makes you have this preference?

Size Comfort Padding Ease of access Fit

Reduces Pain/Discomfort Other ....

Q15 If only carrying webbing, which webbing would you prefer to wear?

Waist Webbing Chest Webbing

Q16 Of the two packs used during this current trial (90 Pattern and AirMesh) which did you prefer? 90 Pattern AirMesh No Preference

Q16b What aspect of that pack makes you have this preference?

Size Comfort Padding Better Thermal Properties Fit

Reduces Pain/Discomfort Other ....

Q17 Which one thing do you feel would most improve the '90 Pattern equipment?

....

Q18 How would you rate the '90 Pattern equipment as an overall system?

Very Good Good Average Bad Very Bad

Questions Regarding Boots.

Q19 Which boots do you most regularly wear while undertaking military activities?
Standard Issue Leather Standard Issue Jungle Your Own

Q20 Would you consider your boots to be broken in? Yes No

Q21 Which boots do you prefer to wear? Standard Issue Your Own

Q21b What aspect of those boots makes you have this preference?
Comfort Padding Flexibility Cost
Reduces Pain/Discomfort Other ....

Q22 How would you rate your boots overall?

Standard Issue	Very Good	Good	Average	Bad	Very Bad
Your Own	Very Good	Good	Average	Bad	Very Bad

Q23 Do you place separate insoles in your boots, and were these issued to you?
Yes, Issued Yes, Not Issued No

Other Issues With Load Carrying.

Q24 Do you feel that carrying loads restricts your ability to complete a set task at the end of a march, either physical (obstacle course, river cross etc) or mental (map reading, rifle shooting)? Yes No

Q25 Which aspect of load carriage most significantly restricts you ability?
Shoulder/Neck Pain Numbness in Hands/Arms Blisters
General Tiredness Lower Limb Pain Injury
Other ....

Q26 Have you ever had time off from active duty due to an injury of any sort?
Yes No

Q27 Do you have a current or previous injury that you feel is worsened or aggravated by carrying loads? Yes No

Appendix 9.4: Transcripts from interview study.

Lower Limb Pain

Part 1: No pain during trial, only knee pain caused by running and sports.

Part 2: No pain caused by carrying loads.

Part 3: No pain during trial, only knee pain whilst cycling. Mild superficial hip pain due to rubbing of webbing.

Part 5: Ankle joint pain while walking, not typical of load carrying, may have been due to treadmill walking.

Part 6: No pain due to load carrying, knee pain from running and sports.

Part 8: No pain from load carrying, ankle pain from sports and running.

Part 9: Mild pain in foot, not typical of load carrying.

Part 10: Heel pain typical while carrying loads and with sports. Mild hip joint pain typical of load carrying.

Upper Limb Pain

Part 1: Shoulder and lower neck pain due to cutting in from pack, typical of carrying loads, pain usually disappears within ½ hour of pack removal.

Part 2: Pain in shoulder, typical of load carrying, goes with time.

Part 3: Shoulder pain, typical of load carrying, goes in 3 hours. Occasional back pain due to load distribution or webbing.

Part 5: Shoulder uncomfortable, typical.

Part 6: Severe lower neck and shoulder pain in effort to keep load forward, typical, goes in few hours.

Part 8: Pain between shoulder blades, typical, goes in few hours.

Part 9: Mild pain in neck, typical. Severe pain in left shoulder due to previous injury, worsened considerably by load carriage, typical pain and only felt while carrying loads. Pain present for quite a while after doffing of pack. Visited the military doctor and GP, military doctor said nothing was wrong with shoulder, GP suggested 2 weeks off active duty and rest from load carriage. Re-injured recently playing in goal during football.

Part 10: Shoulder uncomfortable towards end of trial, typical, goes in few hours.

Blisters

Part 1: During the trial lots formed all over the foot, during training still get blisters but only really on heel and toes. Cause 1-2 days of restricted duty and remain for about 1 week, self-manageable and no clinic visits.

Part 2: No

Part 3: Blisters formed on balls of feet, this is typical of marching but blisters on toes were not typical, no time off or clinic visits, self-manageable.

Part 5: Bad blisters around heel and balls of feet, typical of marching but worse with treadmill walking, self-manageable.

Part 6: Blisters formed during the trial typical of marching or running in military boots. No time off due to blisters but visits to clinic. Clear up within 1-2 days.

Part 8: Blisters formed were typical of marching, usually go in around 3 days.

Part 9: No

Part 10: No

Boots

Part 1: Wears standard issue boots but prefers commercially purchased boots as they have more padding and are more comfortable. Boots were broken in.

Part 2: Wear SI boots, broken in.

Part3: Wear SI boots, broken in. Prefers com boots as are more comfortable and flexible over the whole boot and not just the toes region.

Part 5: Wear SI boots, only 2-3 months old so not broken in.

Part 6: Wear SI boots while training but com boots while on operations as they are more comfortable.

Part 8: SI boots aren't great could make them more flexible. Com boots are better as they decrease pain and blisters.

Part 9: Always wear Com boots as better than SI, more comfortable with padding. No blisters or pain with com boots, mild with SI.

Part 10: Wears SI boots, well broken in. Prefers Com boots as more padding.

Load Carriage Systems

Part 1: Preferred AirMesh LCS as there was a lot less pain in the shoulders and back. Didn't like chest webbing as it cuts into the neck and increased temperature. Improve '90 Pattern by increasing shoulder support and padding.

Part 2: '90 not well integrated as straps from the Bergen make the yoke cut into the neck.

Part 3: Neck pain was caused by chest webbing not waist webbing. Preferred the AM due to increased shoulder padding even though still bad pain. Improve the '90 by increasing padding. Uses a day sack if exercise is less than 1 hour.

Part 5: Only used '90.

Part 6: Only uses '90 but more padding in straps and back needed, apart from that it is a good pack. Straps difficult to manage if too loose the pack sits off the back and pulls on shoulder and neck, if too tight then cuts off circulation.

Part 8: Only used '90.

Part 9: Improve '90 by increasing padding in shoulder. Preferred AM as it was more comfortable and decreased the height of the pack.

Part 10: Improve '90 by increasing padding in shoulder. Prefers AM as it shifts the weight forward and onto the hips, also more padding in shoulders and back. Uses a day sack as it is a good size.

Other

Part 1: Blisters restrict ability to do job successfully. Increasing load, speed and time of march all increase incidence of blisters and upper limb pain.

Part 2: Pain (particularly in shoulders) remains constant with time but increases as more load is carried.

Part 3: Neck pain caused by chest webbing caused by forced forward head position, also cutting in.

Part 5: Time off active duty due to acute injury not caused by but worsened by carrying loads.

Part 6: Increased load and carrying time causes numbness in hands and can't lift arms, this restricts ability to do job successfully.

Part 8: General discomfort remains constant with time but increases if more load is carried. Shoulder pain restricts ability to shoot rifle.

Part 9: Pain in shoulders restricts rifle carriage and aim. Pain in shoulder increases with time and load.

Part 10: If pack is too loose then it pulls on shoulder and causes neck pain.

Appendix 9.5: Grid for answers given from the questionnaire.

	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10
Q1	5yrs	7yrs 4mths	1yr 4mths	5yrs	1yr 6mths	1yr 6mths	1yr 6mths	5yrs 6mths	1yr 5mths	4yrs 9mths
Q1b	Officer Training Cadets	TA Officer Training Cadets	Officer Training	Cadets	Cadets	Officer Training	Officer Training	Officer Training Cadets	Officer Training	Officer Training
Q2	1-3 days/week	1-3 days/week	Every few weeks	Never	Every few weeks	1-3 days/week	1-3 days/week	1-3 days/week	1-3 days/week	1-3 days/week
Q2b	Always	Regularly	Sometimes	Never	Sometimes	Sometimes	Regularly	Sometimes	Sometimes	Sometimes
Q3	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Q3b	Shoulders, Yes, 2/3 Neck, Yes, 1/2 Arms, No, 1/2	Shoulders, Yes, 4	Shoulders, Yes, 3	Shoulder, Yes,2 Upper back, Yes, 2	Shoulder, Yes, 3 Neck, Yes, 4 Upper back, Yes, 3	N/A	Shoulders, Yes, 2	Shoulders, Yes, 2 Neck, No, 2	Shoulders, Yes, 4 Neck, Yes, 3 Arms/hands, Yes, 2	Shoulders, Yes, 2 Neck, Yes, 2
Q4	Load Time	Distance	Load	Speed	Load Time Distance	Load	Distance Speed	All	All Terrain type and gradient	All
Q5	Greater 2 hrs	24 hrs	0-30 mins	Straight away	0-30 mins	Greater 2hrs	0-30 mins	30-60 mins	24hrs	0-30 mins
Q6	Yes	No	No	Yes	Yes	Yes	No	No	Yes	Yes
Q6b	Leg, 2	N/A	N/A	Foot, Yes, 2	Foot, Yes, 3 Knee, No, 1	Leg, Yes, 2			Foot, Yes, 5 Ankle, No, 3 Leg, Yes, 2	Foot, Yes, 2
Q7	No	No	No	Yes, sports	No	No	No	No	No	No
Q8	Yes, Typical	No, Not Typical	Yes, Typical	Yes, Typical	Yes, Typical	No, Not typical	Yes, Not typical	No, Typical	Yes, Not typical	No, Typical
Q9	Toes Heel	Heel	Heel	Toes	Heels Balls of feet	Balls of feet	Heel Balls of feet	Heel	Heel	Heel
Q10	6-24 hrs	1-3 days	1-3 days	1-3 days	3+ days	1-3 days	1-3 days	6-24 hrs	3+ days	1-3 days
Q11	Self-managable	Self-managable	Self-managable	No Action	Self-managable	Self-managable	Self-managable	Self-managable	No action	Self-managable
Q12	Yes, Typical	Yes, Typical	Yes, Typical	No, Typical	Yes, Typical	No, Typical	Yes, Typical	Yes, Typical	No, Not typical	Yes, Typical
Q13	Speed	Distance	Time	Time	All	Load	Load	Time Distance	All Wet socks	Load Distance
Q14	Yes, Lowe Alpine	Yes	Yes, Lowe Alpine	No	No	Yes, Eurohike	Yes, Outwell	Yes, Kammor	Yes, Lowe Alpine	Yes, Vango
Q14b	Other	Other	Other	N/A	N/A	Other	Other	Other	Other	Other
Q14c	Ease of access Reduces pain/discomfort	Comfort	Comfort	N/A	N/A	Padding	Comfort Fit	Comfort Padding Reduces pain/discomfort	Comfort Padding Fit Reduces pain/discomfort	Comfort Reduces pain/discomfort
Q15	Waist	Chest	Waist	Chest	Chest	Chest	Chest	Chest	Chest	Waist
Q16	AirMesh	AirMesh	AirMesh	AirMesh	AirMesh	AirMesh	AirMesh	AirMesh	AirMesh	No preference
Q16b	Padding Reduces pain/discomfort	Comfort	Comfort	Comfort	Padding Thermal properties Fit	Comfort Padding Reduces pain/discomfort	Thermal Properties	Comfort Padding	Comfort Padding Reduces pain/discomfort	N/A
Q17	Better waist protection	Chest strap	Better waist belt	Improve comfort	Less weight on Shoulders	Better shoulder padding	Back like on AirMesh	Better fit	N/A	Better shoulder padding
Q18	Good	Bad	Good	Average	Average	Very Good	Good	Good	Average	Average
Q19	Own	Leather	Only Leather	Only Leather	Only Leather	Only Leather	Own	Leather	Leather	Only Leather
Q20	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Q21	Own	Own	N/A	N/A	N/A	N/A	Own	Own	Own	N/A
Q21b	Comfort Padding	Comfort	N/A	N/A	N/A	N/A	Comfort Flexibility	Comfort Flexibility	Reduces pain/discomfort	N/A
Q22	Average Very good	Very Bad Very Good	Good N/A	Good N/A	Bad N/A	Very Good N/A	Bad Average	Good Very Good	Bad Good	Good N/A
Q23	Yes, Not issued	Yes, Issued	Yes, Issued	N/A	No	Yes, Issued	Yes, Issued	Yes, Issued	Yes, Issued	No
Q24	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes
Q25	Blisters	Shoulder/neck pain	General tiredness	Injury	Blisters	Numbness in hands	General Tiredness	Shoulder/neck pain	Blisters	Shoulder/neck pain
Q26	No	No	Yes	No	No	No	No	No	No	No
Q27	No	No	No	No	No	No	No	No	No	No

Appendix 10.1: Comfort questionnaire used during the study. Questions 1, 2, 3, 4 and 5 used for Attwells (2006), questions 1 and 6 used for this current study.

Comfort questionnaire

Loughborough University work with the MoD looking at military equipment. We ask that you please fill in this form to let us know how you feel following your CFT. All forms should be returned to your PSR or member of Loughborough University on site. Any questions you have may be directed to Renee Attwells (R.L.Attwells@lboro.ac.uk) or Stewart Birrell (S.A.Birrell@lboro.ac.uk). We have asked for your details should we need to contact you at a later date or when we are doing further research.

Disclaimer

I understand what I have been asked to do and am aware I may ask any questions or withdraw at any time

Name... Sex M / F

Signature.....................................

Contact Details: (Ph)......................... and/or (Email) ....

Date of Birth......................... Time in Army/OTC.........yrs.........months

Boots worn on CFT (please circle) Issued / Own

Weight carried (circle) 35lb (~16kg) / 55lb (~25kg) / Other (please specify).........

Webbing used Belt Order / Vest webbing

Backpack carried? Y/N If yes then Day Sack / Short back / Long back / Other

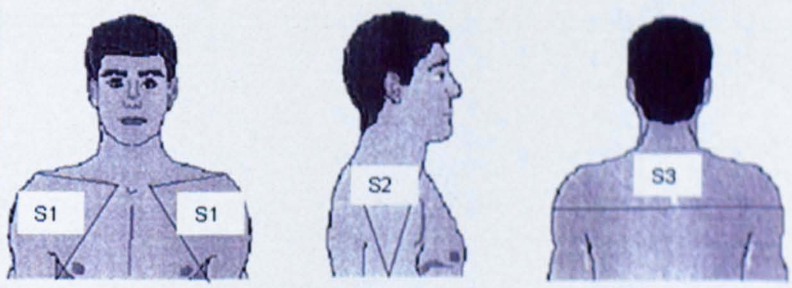
Have you used Zinc Oxide tape? Y/N If so where...

PLEASE COMPLETE BOTH SIDES OF THE FOLLOWING SHEETS

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable

Shoulder Comfort

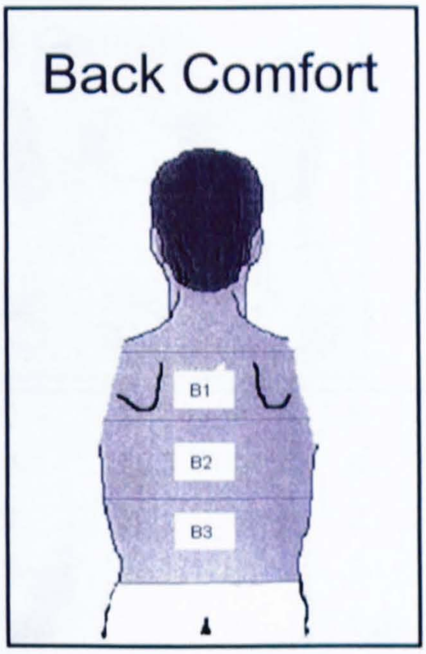


Please Circle your rating

S1 – Front of Shoulders	1	2	3	4	5
S2 – Top of Shoulders	1	2	3	4	5
S3 – Neck	1	2	3	4	5

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable

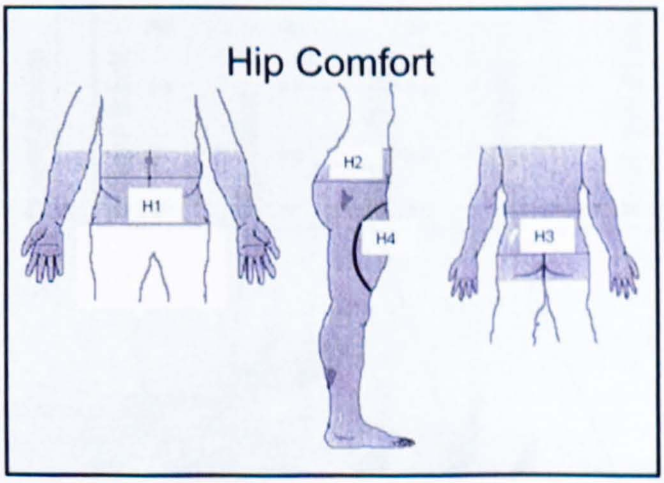


Please Circle your rating

B1 – Upper Back	1	2	3	4	5
B2 – Mid Back	1	2	3	4	5
B3 – Lower Back	1	2	3	4	5

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable



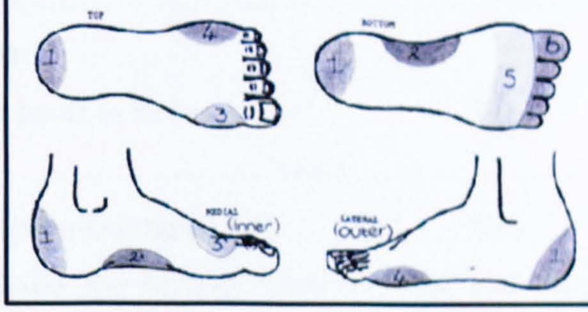
Please Circle your rating

H1 – Front of Hips	1	2	3	4	5
H2 – Side of Hips	1	2	3	4	5
H3 – Top of backside	1	2	3	4	5
H4 – Thigh	1	2	3	4	5

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable

Foot Comfort



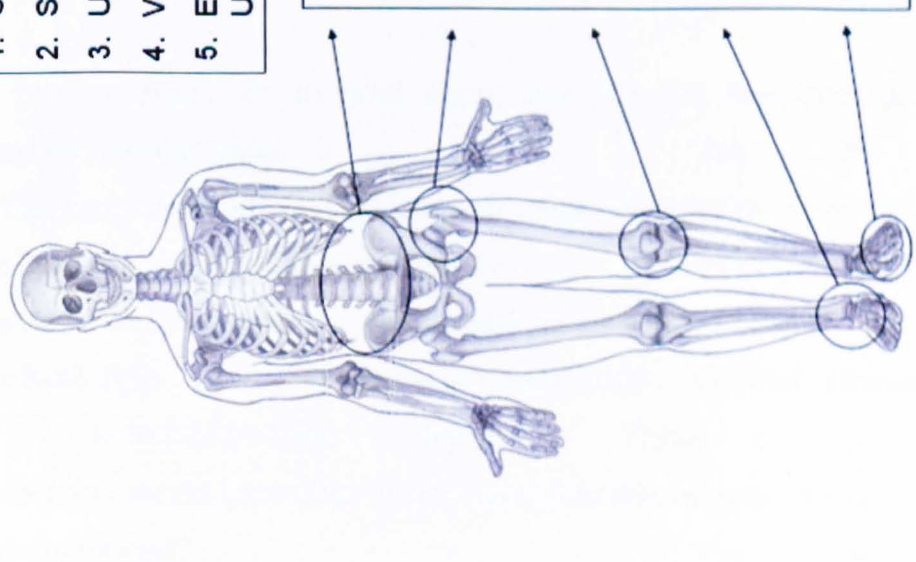
Please Circle your rating

1 – Heel	1	2	3	4	5
2 – Arch of foot	1	2	3	4	5
3 – Inner side of Big Toe	1	2	3	4	5
4 – Outer side of little toe	1	2	3	4	5
5 – Balls of feet	1	2	3	4	5
6 – Underneath Toes	1	2	3	4	5

How do your **Joints** and **Bones** feel right now?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable

Lower Back	1	2	3	4	5
Hip Joint	1	2	3	4	5
Knee Joint	1	2	3	4	5
Ankle Joint	1	2	3	4	5
Foot (not Blisters)	1	2	3	4	5



Appendix 10.2: Additional questions for exercise dropouts.

Q1. What was the main reason for your withdrawal from this exercise? ....

....

....

Q2. If withdrew due to blisters:

Q2a. Would you consider your boots to be broken in? Yes / No

Q2b. How old are your boot? .... Years .... Months

Q2c. Do you typically get blisters when marching? Yes / No

Q2d. Does carrying load increase the severity (number, size and frequency) of blisters and / or the pain resulting from these blisters? Yes / No

Q3. If withdrew due to upper / lower limb injury / discomfort:

Q3a. Which part of the upper / lower limb is particularly affected? ....

....

Q3b. Do you feel this pain / discomfort when: Marching Playing Sports Everyday Life Military Exercises Only When Carrying Loads

Q3c. Is this feeling typical of that while marching? Yes / No

Q3d. Have you visited a doctor due to this injury / discomfort? Yes / No

Q3e. Have you ever had time off due to this injury / discomfort? Yes / No

Q3f. Does carrying loads increase this pain / discomfort? Yes / No

Q3g. Which of the following may increase this pain / discomfort?
Increased Load Increased Time Increased Distance
Increased Speed Other...

Q4. Do you have a current or previous injury that you feel resurfaces or is aggravated by carrying loads? Yes / No

Q5. Do you feel that carrying loads restricts your ability to complete a set task at the end of a march, either physical or mental? Yes / No

Q6. What aspect of load carriage most significantly restricts your ability?
Shoulder/Neck Pain Numbness in Hands/Arms General Tiredness
Blisters Lower Limb Pain Injury Other ....

Q7. Do you feel you would have been able to complete this exercise if you were not carrying this load? Yes / No

Appendix 10.3(a): Load carriage injury data collection information sheet.

Why are we collecting this data?

Two years ago the Ministry of Defence asked Loughborough University to look into the affects that carrying loads has on injuries in the military. This work forms part of this research.

Combat related injuries represent only a very small number of the total injuries sustained by members of the military. The rest of them are made up from a variety of training injuries and accidents.

This research will hopefully highlight the specific problems that injuries or discomfort caused by carrying loads plays, with a view to reducing or at least managing the inevitable risks of load carriage.

Do I have to take part?

No you don't, you have the right to not have your injury recorded and even removed after the data has been collected. But, your help would be appreciated and may go some way to determining the problem that carrying loads causes.

If you have any questions, would like to know more about this research or would like your data to be removed then contact Stewart Birrell of Loughborough University on 01509 228484 or at S.A.Birrell@lboro.ac.uk.

Thanks for your help.

Appendix 10.3(b): Load carriage injury data collection sheet.

Name / Soldier No: ....

Date of treatment: ....

Date injury first materialised: ....

Type of injury sustained: ....

....

During which activity was the injury sustained: ....

....

Cause of injury: ....

....

Suggested treatment: ....

....

Could this injury have been caused or exacerbated by load carriage: ....

....

Is this the first time this injury has materialised: Yes / No (If No how often)

Very Often Often Occasionally Rarely Very Rarely

Is this injury / discomfort typical of that while carrying loads: Yes / No

Has this injury restricted your ability to carry out the exercise: Yes / No

Disclaimer

I (the above named person) give permission for this data (collected on the above date) to be used by Loughborough University to research injuries in the military due to load carriage, I do so freely and understand I have the right to withdraw data at any time.

Signed: ....

Appendix 11.1: Load carriage injury and discomfort questionnaire.

Load Carriage Questionnaire

The purpose of this questionnaire is to collect information on discomfort as a result of carrying loads. The questions refer to your recent military exercise training undertaken during Summer 2005. However, we are also interested in your other experiences of carrying loads. The answers given will aid research into military load carriage injuries and also form a report for Welbeck College.

Questions should be answered by circling at least one response and give further details when asked. Some questions will ask you to rate your comfort while carrying loads, for these use the scale provided. Anything you write will be treated as strictly confidential, so please answer questions as fully and as honestly as you can.

General Questions

Q1 Please supply some brief details regarding yourself.

Height .... Weight .... Age .... Gender *M / F*

Q2 General questions about the military exercises you conducted last summer.

a) How many days did you spend on these summer exercises? .... days

b) How many of these days involved load carriage? ....days

c) Which webbing did you use most regularly? *Waist* *Chest*

d) Which backpack did you use most regularly? *Bergen* *Day Sack*

e) What weight did you typically carry? .... kg

f) Which boots did you usually wear? *Standard Issue* *Other*

Q3 Prior to these exercises how much experience carrying loads did you have?

None *Little* *Some* *Plenty* *Lots*

Q4 Which service of the Military are you interested in joining?

Royal Navy *Army* *Royal Air Force* *Civil Service*

Questions Regarding the Upper Limb (shoulders, neck, hands/arms)

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

Q5 During typical load carriage how would you rate the comfort of your shoulder?

1 2 3 4 5

Q5b During typical load carriage how would you rate the comfort of your neck?

1 2 3 4 5

Q5c During typical load carriage how would you rate the comfort of your hands/arms?

1 2 3 4 5

Q6 Rate each of the following out of 10 as to which, in your experience, most increases the upper limb discomfort that you feel when carrying loads.

Least effect ⟶ Most effect

Weight of Load	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Time Carried	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Distance Hauled	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Speed of March	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Gradient/Terrain	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

Q7 After the load has been removed how long does it take for the initial discomfort to disappear?

Straight Away *1-30 Minutes* *30-60 Minutes* *Over 1 hour*

Q8 In the days/weeks following load carriage do you usually have any lingering upper limb discomfort due to carrying the load?

Yes *No* *Can't Remember*

Q8b If yes, <u>where</u> abouts was this discomfort felt and <u>how many</u> days did it last?

Where ……………………………………………… *Lasted* … …………… *days*

Q8c Did you have this discomfort assessed by a medical professional? If yes, what was the recommended treatment?

Yes ……………………………………………………………………… *No*

Q9 During load carriage do you feel you have a restricted ability to lift your <u>arms</u> or turn your <u>head</u>? *Arms* *Head* *Neither* *Both*

Q10 During load carriage have you ever experienced numbness in your hands or arms? *Yes* *No* *Don't Know*

Q11 Do you worry about the long term implications carrying loads may have on your upper limb? *Yes* *No* *Don't Know*

<u>Questions Regarding the Back (both the upper and lower back)</u>

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

Q12 During typical load carriage how would you rate the comfort of your <u>upper back</u>?

1 *2* *3* *4* *5*

Q12b During typical load carriage how would you rate the comfort of your <u>lower back</u>?

1 *2* *3* *4* *5*

Q13 In the days/weeks following load carriage do you usually have any lingering back discomfort due to carrying the load?

Yes *No* *Can't Remember*

Q13b If yes, <u>where</u> abouts was this discomfort felt and <u>how many</u> days did it last?

Where .... *Lasted* ... . *days*

Q13c Did you have this discomfort assessed by a medical professional? If yes, what was the recommended treatment?

Yes.. *No*

Q14 Do you feel that while carrying loads you have restricted flexibility/movement in your back? *Yes* *No* *Don't Know*

Q15 Do you worry about the long term implications carrying loads may have on your back? *Yes* *No* *Don't Know*

<u>Questions Regarding the Lower Limb (hip, knee, ankle, feet (not blisters))</u>

Comfort	Rating
Comfortable	1
Slightly Uncomfortable	2
Uncomfortable	3
Very Uncomfortable	4
Extremely Uncomfortable	5

Q16 During typical load carriage how would you rate the comfort of your <u>hip joints</u>?

1 *2* *3* *4* *5*

Q16b During typical load carriage how would you rate the comfort of your <u>knee joints</u>?

1 *2* *3* *4* *5*

Q16c During typical load carriage how would you rate the comfort of your <u>ankle joints</u>?

1 *2* *3* *4* *5*

Q16d During typical load carriage how would you rate the comfort of your <u>feet</u>?

1 *2* *3* *4* *5*

Q17 In the days/weeks following load carriage do you usually have any lingering lower limb discomfort due to carrying the load?

Yes *No* *Can't Remember*

Q17b If yes, <u>where</u> abouts was this discomfort felt and <u>how many</u> days did it last?

Where .... Lasted ... . days

Q17c Did you have this discomfort assessed by a medical professional? If yes, what was the recommended treatment?

Yes.. No

<u>Questions Regarding Blisters</u>

Q18 Do you typically experience blisters when undertaking military activities such as marching or carrying loads? *Yes* *No* *Don't Know*

Q19 Where on the foot do you most often get blisters? (Circle as many as required)

Toes *Heels* *Balls of Feet* *Sides of Feet/Toes*

Q20 How restricting would you rate the blisters that you typically experience on your ability to march?

Not at all *A Little* *Some* *Quite a Bit* *Very Much*

Q21 How would you treat blisters if or when they occur?

Clinic Visit *Time Off* *Self-Manageable* *No Action*

<u>Other Questions</u>

Q22 Do you feel that carrying loads reduces your ability to complete a set task at the end of a march, for example either <u>physical</u> (obstacle course, river cross etc) or <u>mental</u> (map reading, rifle shooting)?

Physical *Yes* *No* *Don't Know*

Mental *Yes* *No* *Don't Know*

Q23 Rate each of the following out of 10 as to which, in your experience, most increases the general discomfort that you feel when carrying loads.

	Least effect	→							Most effect
Weight of Load	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Time Carried	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Distance Hauled	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Speed of March	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Gradient/Terrain	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

Q24 Which aspects of load carriage most significantly restricts your ability?

Shoulder/Neck Pain *Numbness in Hands/Arms* *Blisters*
General Tiredness *Lower Limb Pain* *Injury*
Back Pain *Other* ....

Q25 Do you feel that carrying loads increases your risk of falling or tripping while marching? *Yes* *No* *Don't Know*

Q26 Do you worry that carrying loads will increase the severity of any potential fall while marching? *Yes* *No* *Don't Know*

Q27 Do you place cushioning insoles inside your boots? *Yes* *No*

Q28 Do you regularly carry loads in packs other than the standard issue 90 Pattern, say those brought off the commercial market? *Yes* *No*

Q29 Do you have a current or previous injury that you feel is triggered by or aggravated by carrying loads? If yes, what type of injury is this?
Yes .... *No*

Q30 Do any of the feelings of discomfort mentioned occur during un-military related activities? If yes, where is this discomfort and during which activity?
Yes / *No* *Where* ....
Which Activity ....